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INAUGURAL ADDRESS

BY THE PRESIDENT,

Mr. JOHN WEST, M.Inst.C.E.,

On 11th JANUARY, 1890,

AT THE GRAND HOTEL, MANCHESTER.

MANCHESTER:
HERALD & WALKER, PRINTERS, BACK POOL FOLD, CHAPEL WALKS,
1890.

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1890.

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INAUGURAL ADDRESS.

Gentlemen,

My first and pleasant duty is to thank you for the honour and distinction you have conferred upon me by electing me President of this very important Association of Engineers, consisting of members representing all the principal branches of engineering in Manchester and the surrounding districts.

You will observe, by looking at the circular calling this meeting, that I intend speaking to you to-night upon a few topics and engineering problems, some of which may apply to the whole universe, but all of which intimately concern ourselves and the public generally, in this important centre of engineering industry.

During the last fifty years science and engineering have made gigantic strides, and everywhere there has been a continuous discovery of great and invaluable scientific truths. Relationships, which can be reduced to exact laws, have been shown to exist between the various forces of nature, and these laws are now recognised to be of fundamental importance in the great questions of the utilisation of energy, and the directing of the forces of nature to the service of man.

THE LATE DR. J. P. JOULE.

To no scientific discoverer of the present age are we, as an engineering profession, more deeply indebted than to our lamented and distinguished townsman, Dr. James Prescott Joule, the discoverer of the mechanical equivalent of heat. Some of you have been highly favoured by having the privilege of joining in company with this great philosopher, and therefore you must very deeply feel his irreparable loss. Most of you are aware that he was a pupil of Dr. Dalton, another Manchester man of fame, who first established the atomic theory, and the principle of the indestructibility of matter. Dr. Joule first indicated the discovery of a law in the relationship between heat and work, in a paper read to the British Association, at Cork, in 1843, but he was careful to show that he wished to make

more crucial experiments than he had up to that time devised, and throughout all his labours he has shown the truest scientific spirit in the accuracy of his work and his jealousy for truth. In this paper he adds the now memorable words, "I shall lose "no time in repeating and extending these experiments, being "satisfied that the grand agents of nature are by the Creator's "fiat indestructible, and that, wherever mechanical force is "expended, an exact equivalent of heat is always obtained." Dr. Joule's researches were not confined to one subject. In the Royal Society's list there are 97 papers which bear his name alone, besides 20 others in which he is associated with Sir William Thomson, Sir Lyon Playfair and Dr. Scoresby.

Among the subjects embraced in these numerous papers are electro-magnetism, a new theory of heat, the mechanical equivalent of heat, the electrical origin of calorific heat, shooting stars, air engines, the construction of sailing vessels, a method of testing the strength of steam boilers, the utilisation of sewage, &c., &c. We find that at the early age of 19, Dr. Joule began to show signs of exceptional talent by reading a paper upon a new electro-magnetic engine (thereby setting an example to young men of the present generation), and from that period he continued his scientific investigations until failing health curtailed his energy. I believe that no man worked for science with more purity of motive than Dr. Joule. He sought neither profit nor honours, but in spite of his retiring disposition the latter were showered upon him in great abundance. He certainly has been a great benefactor to the human race, and we, as engineers, are especially indebted to him for the result of his researches, which have proved to be of the most practical order and of the highest scientific value. He, no doubt, enjoyed the pleasure and gratification of knowing that his efforts had resulted in universally benefitting mankind, not only for the present, but for future generations. We all feel (and have to lament the loss) that a valuable life full of honour has ended its course among us, leaving behind it an example of untiring and persistent energy, and of patience in the pursuit of knowledge undertaken for the pure love of science, at the same time acknowledging the great Creator in all things, and preparing for a glorious hereafter.

THE LATE T. A. WALKER, ESQ.

We also have to record and deplore the loss by death of Mr. Thomas Andrew Walker, a gentleman who only recently came amongst us as the great and enterprising contractor for the Ship Canal, a scheme in which we are all interested. The Ship Canal Company were very fortunate in securing a contractor who was possessed of such a large and sound experience, obtained in the carrying out of extensive works in various parts of the world, one of his most difficult tasks being the completion of the Severn Tunnel, about which he remarks, in the preface to the book written by himself to record his experience on that work, that "One subaqueous tunnel is quite enough for a life-time." I would recommend all of you to read this book, when you will gather a better idea of the ability and sterling character of the great contractor.

It was thought by many that the Ship Canal undertaking could not be carried out in the time promised; but it was soon observed that the Chief Engineer, Mr. E. Leader Williams, and the Contractor, Mr. Walker, intended to make use of every possible mechanical appliance that could be devised to facilitate the quick despatch and punctual completion of this modern piece of engineering, and most of you have had the pleasure of witnessing, for the first time in your lives, the great difference in speed between manual and mechanical excavating. We may, with pardonable pride, rejoice over the fact that mechanical engineers have, by their skill, brought so many labour-saving appliances to assist in this work. It is of the greatest importance that all great works should be carried out as quickly as possible, so that investors may soon receive a return for the capital they have invested in the undertaking from profit actually earned by the working of the concern.

To give you a better idea of the magnitude of this undertaking and the mechanical appliances used, Mr. Leader Williams has kindly given me full particulars of the several machines, &c., in use on the work in December, 1889, which I believe will interest you:—

Number of Steam Navvies employed, including 3 German Navvies, 4 French Navvies, and 58 Ruston and Proctor's Navvies	96

Number of Locomotives	166
Number of Steam Cranes	162
Number of Portable and other Engines	127
Number of Steam Pumps	186
Number of Wagons	5874
Number of Pile Engines	40
Length in miles of temporary Railway	213
Number of Men and Boys Employed	11489
Horses	182
Tons of Coals used on the excavation each month	10000

TECHNICAL EDUCATION.

Technical education, especially in connection with engineering pursuits, has received the special consideration of our association, and a very valuable scheme was devised, and a course of systematic study prepared and recommended, for guiding youths engaged in engineering workshops in their study of the different branches of science applicable to their various occupations.

The book containing the scheme having been compiled by men remarkable for practical experience in combination with scientific knowledge (the latter having been obtained in many instances under almost overwhelming difficulties) is looked upon as a valuable authority on the subject, and I have reason to believe that the advice given in our pamphlet on the "Technical Education of Engineers," has been very advantageous to many young men in Manchester as a guide in their work and studies.

All those interested in technical education—and certainly every engineer ought to be enthusiastic on the subject—will be glad that an act was passed last session to facilitate the provision of technical instruction by any local authority, whereby aid may be obtained from the local rates to provide almost any kind of instruction found desirable to meet the wants of the local industries of any particular district.

The first clause of the new act reads thus:—

"A local authority may from time to time out of the local "rate supply or aid the supply of technical or manual instruc- "tion to such extent and on such terms *as the authority think* "*expedient*."

I consider that there is a wide difference between training youths who are to follow chemical or artistic pursuits, and those

intended for engineers. The former may make themselves fairly efficient in the laboratories of the Technical School, and be able to utilise immediately the knowledge gained there with advantage to themselves, but I fear that few youths intended for engineers, could spend any time beyond the ordinary school years in our existing Technical Schools without being actual losers, and I am of opinion that our Technical School system will require very considerable improvement before it will efficiently meet the requirements of the case; but now is the opportunity for us to act and do that which (as the Act suggests) is most expedient in our own district. Probably our Technical Schools might form a basis upon which a better scheme could be founded, but the question is one of great difficulty. Then there is Owen's College, which has splendid rooms well fitted up with various kinds of machinery, and ought to be the centre of the engineering life of the district; but from some cause or other I find that those most likely to be benefitted by the knowledge that might be gained there, scarcely know that engineering is taught there at all, and are quite unaware of the excellent apparatus at their disposal.

To my surprise I see, from the last annual report of the Principal, that there were only 41 students attending the engineering classes last year and 35 in the engineering laboratory, the probability being that the former number includes the majority of the latter; whereas the chemical students are counted by hundreds.

There is no doubt it is necessary, if we are to hold our own as a nation, that we should give our youths every help that can be given in the way of education, to fit them for utilising to the best advantage the teaching of practical experience, without which an engineer cannot be made at any price. At the present time I believe that, after a lad has received a good, sound, primary education the best plan is to send him at once into the workshop, where he will see things going on in a practical way, and will have to handle the tools with the understanding that everything he does has a commercial value. This will elevate his mind and call out his abilities far more than the practice adopted in many Technical Schools of making disproportionate models and things that are known to be useless and of no value. Then he

should attend the evening classes, so as to engraft the science of his trade upon his practical experience. This is the course which I am pursuing, at the present time, with my own sons, believing it to be far preferable to any other method available in Manchester up to the present.

ELECTRICITY.

Lighting by electricity has now been before us for a very long period. Some of us remember seeing the display at the Paris Exhibition, in the year 1878, and again at the Crystal Palace, in comparison with gas lighting; also the large experiment, carried on over a long period, on the Thames embankment with arc lights. Since then the electric light has been gradually advancing in favour, and fabulous sums have been invested to further its advancement.

In 1882 an Act was passed to grant electric lighting companies power to supply electricity from central stations, and to lay conductors from their works to the consumers' premises, in a similar manner to the method used in the supply of gas. The restrictions imposed upon the companies by this Act were considered too severe, and no doubt prevented works being started; but during the year 1888 they were released from what they called the "old iron" clause of that Act, which stipulated, that, after the expiration of 21 years, the local authority, in whose district they were situated, could force them to sell their plant at the market value without any regard to the goodwill; but they obtained relief through the Act of 1888, which not only prolonged the period to 42 years, but also directed that, in the event of transfer, the Company should be treated as a going concern. This has encouraged those in favour of electric lighting, and companies have sprung up in London and the provinces to lay down plant for supplying the light. In some cases, where the gas works belong to the municipalities, they themselves have obtained powers to supply the electric light as well as gas. At the present time there are ten electric lighting companies formed for lighting London, with a united capital of over three millions sterling, and these companies are now erecting buildings, and putting down steam boilers, engines, electrical plant, and mains for supplying the various districts.

Electricity is supplied by the various companies on the following different systems, viz :—

1. The direct continuous current.
2. Do. do do storage system.
3. The alternate-current transformer system.

The first two systems are advocated by Mr. Edison, and are to have several stations and mains to send out current of low potential. In the first case the electricity is supplied direct, and in the second it is used through storage batteries. This system is much recommended for small areas, as the machinery can be thrown off for a period of from six to nine hours out of the twenty-four, when the demand for electricity is at its least, and although it is said that from 15 to 20 per cent. of electricity is lost by this system, that is compensated for by the diminution in expenditure for wages, when steam power is employed.

The alternate-current system is the high tension system, advocated by Mr. Ferranti, engineer to the London Electric Supply Corporation, whose station is at Deptford, where very large and powerful machinery is being erected. The current of electricity, when the large dynamos and engines are put in action, will be conveyed from the station at a pressure of 10,000 volts to local stations situated at different points of London, where there are transformers to reduce the pressure to 2,400 volts, and, before entering the consumers' premises, it will be further reduced by other transformers to 100 volts, this being to meet the Board of Trade requirements.

Electric lighting by incandescent lamps of 10 to 16-candle-power is now used with good effect in Hotels, Banks, Restaurants, Theatres, Clubs, Printing Offices, and some large residences, and may be looked upon as a rival to gas. Very great credit is due to electrical and mechanical engineers for producing very superior steam and gas engines and dynamos, which work with a minimum of friction, and, owing to their long bearings and substantial general construction, they will run without risk for many consecutive hours, and give a much more steady light than formerly.

The charges for electricity range from 7d. to 8d. per Board of Trade unit of 1,000 watts, and some companies will not give a

supply to a consumer under a minimum charge of £14 per annum.

While it is admitted that electricians have made some progress in perfecting machinery for securing a better and more regular supply of electricity, it must not be forgotten that improved lighting by gas has also made very rapid strides. I had the pleasure 13 years ago of reading a paper before a Philosophical Society upon the "Economic Consumption of Gas," and again, during the year 1882, at the Smoke Abatement Exhibition in this City, where I displayed a number of defective burners that had been used by the consumers, and compared them against the more recent and improved burners then obtainable, and it was found that a large number of consumers were not getting anything like the illumination out of the gas that it would give even with a good ordinary burner. Since that period, two new systems of burners have been perfected. I refer to the regenerative burners of Siemens, Sugg, Wenham, Fourness, and others, and to the incandescent burners of Welsbach, Clamond, and others.

These burners have come into general use, particularly the regenerative kind, and from them a better light can be obtained with from half to one-third the quantity of gas. I have been favoured with the result of some experiments, made by my friend Alexander Smith, Esq., of Aberdeen, with regenerator burners of suitable size for lighting halls, shops, and large rooms, as follows:—

"By consuming 10 cubic feet of gas per hour in one of these "lamps a light equal to 155·2 candles was obtained, or 15·52 "candles for each cubic foot of gas consumed per hour. This "result was obtained with gas, which, when tested according to "the method prescribed in the Gas Works Clauses Act, gives a "light equal to 5·6 candles for each cubic foot, thus showing a "gain of 9·92 candles for every foot of gas per hour when used "by these lamps, or a gain of over 177 per cent."

Similar tests have been made with London Gas as follows:—

Wenham Regenerator Gas Lamps. Lighting power with ordinary London 16 candle gas, taken from tests made by Professor Wm. Foster, M.A. F.R.C.S., formerly Gas Examiner to Metropolitan Board of Works.

Size.	Consumption per hour.	Illuminating power without reflector.	Illuminating power with plain opal reflector.
No. 0	4 cubic ft.	21 candles = 5·5 per ft.	34 candles = 8·5 per ft.
1	6 ,,	58 ,, = 9·2 ,,	78 ,, =12·4 ,,
2	10 ,,	119 ,, =11·9 ,,	164 ,, =17·1 ,,
3	12 ,,	— —	193 ,, =16·1 ,,
4	24 ,,	289 ,, =12·0 ,,	402 ,, =16·7 ,,

Messrs. Sugg and Co., London, who make high power lamps of various sizes, whereby 12 candles are obtained per cubic foot, also make lamps to consume small quantities of gas, suitable for small rooms, producing excellent results, as will be seen from the following :—

Sugg's Patent "Aladdin" Lamp consuming gas at the rate of 3 cubic feet per hour. Lighting power with ordinary London 16 candle gas taken from tests made by Professor Wm. Foster, M.A., F.R.C.S., formerly Gas Examiner to Metropolitan Board of Works.

Size.	Consumption. per hour.	Illuminating power without reflector.	Illuminating power with cardboard reflector.
Aladdin.	3 cubic feet.	19·2 candles = 6·4 per ft.	28·1 candles = 9·3 per ft.

Welsbach Incandescent Gas Lamps. Lighting power with ordinary London 16 candle gas, taken from tests made by Professor Carlton J. Lambert :—

"I have just completed a photometric test of the new mantles "which you lately sent me. I have tried them at pressures "ranging from ½in. to 1½in., and the mean of a number of "experiments gives an illuminating power of 28·8 standard "candles with a consumption of 3 cubic feet of London 16 "candle gas. This gives the very high duty of 9·6 candles per "cubic foot."

I will now compare the relative cost of gas and electricity with equal light from each.

Eminent electricians state that a 16-candle-power incandescent lamp is calculated to last about 1000 hours, and would absorb 60

Board of Trade units of electricity in that time. The cost of 60 units at 8d. per unit, the usual Board of Trade limit of charge, would be 40/-, to which must be added 3s. 9d. the cost of the lamp, which make a total of 43s. 9d. per 60 units.

To make the comparison clear I will give you the cost of gas in London, Manchester and Aberdeen to produce the same amount of light, both with ordinary burners and regenerator burners. (See Table on the opposite page.)

It may be said that I have compared the electric light with both the best ordinary and regenerator burners ; to this I can only reply that these burners are within the reach of all consumers, and that it would be to their great advantage to adopt them.

It must also be noted that I have compared the gas with an electric lamp which is assumed to give the same light throughout the 1000 hours, but such is not the case, as we find, after they have been used for a time, that the carbon filaments get volatilized and deposited on the glass, consequently the size of the filament is diminished and the surface of illumination reduced ; the resistance of the filament would also be increased and the intensity of the incandescence decreased for a given power; the carbon on the glass further reducing the light. These facts are confirmed by the experiments of Mr. W. H. Pierce, who states that the ordinary commercial lamps, consuming 3·54 watts per candle-power when new, require 6·1 watts per candle-power after burning 900 hours, the mean absorption being 5·25 per lamp. Stated the other way, it appears that the candle-power of the lamps after burning 900 hours is only 58·5 per cent. of the initial duty, and the mean value of a lamp during its life is only 67 per cent. of that which it possesses when new. Assuming an average use of 4 hours per day for a lamp, this means not only that all incandescent lamps must be renewed before 225 days, when their luminosity is little more than half what it was when new, but taking all the lamps in an establishment together, three should be provided to do the work of two if the intended average lighting effect is to be maintained.

I am prepared to admit that the introduction of the electric light would be advantageous compared with gas consumed in ordinary burners, when the room is low-pitched, without any means of ventilation, and where a number of people are

COMPARISON OF COST between GAS and ELECTRICITY.

The illuminating power and price of gas per 1000 cubic ft. as supplied in London Manchester and Aberdeen.

ELECTRICITY.	One Incandescent Lamp of 16 candle power requires 60 watts per hour, or 60 Board of Trade units every 1000 hours, which at 8d. per unit (the price now charged by the House to House Electric Supply Co., Kensington, and the Electric Supply Co., Liverpool) amounts to 40s. 0d. To which must be added the cost of lamp, 3s. 9d.				Equivalent light in candles for one hour.	Comparative Cost.	Ratio of Cost.
					16,000	s. d. 43 9	8·75
WITH REGENERATIVE GAS BURNERS.	Quality of gas.	No. of cubic feet required to produce 16 candle power per hour.	No. of cubic feet required for 1000 hours.	Price of Gas.			
				s. d.			
Aberdeen	28 candles	1·44 cubic feet	1,440 cubic feet	3 6	16,000	5 0½	1
Manchester .. .	20 ,,	2 ,,	2,000 ,,	2 6	16,000	5 0	1
London	16 ,,	2·5 ,,	2,500 ,,	2 6	16,000	6 3	1·25
WITH ORDINARY GAS BURNERS.							
Aberdeen	28 ,,	2·88 ,,	2,880 ,,	3 6	16,000	10 1	2
Manchester	20 ,,	4 ,,	4,000 ,,	2 6	16,000	10 0	2
London	16 ,,	5 ,,	5,000 ,,	2 6	16,000	12 6	2·5

assembled assisting in the vitiation of the air; at the same time I am bound to say, that by the adoption of the regenerative gas burners previously referred to, not only would the maximum illuminating power per cubic foot of gas be obtained, but the products of combustion would be carried away without ever being permitted to enter the room, and the warm vitiated air would be removed as it rose to the ceiling.

It appears to me that some people prefer the electric light for reasons outside its advantages as a lighting agent; one man prefers it because of its value as an advertisement, another because it is fashionable, and so on; however, let the cause be what it may, I see no reason at all why they should not have it, if they prefer it, and like to pay for it.

I will now lay before you my views as to the cheapest and best way of producing and delivering electricity to the consumer under varying circumstances.

I am informed that in one town a complete electric lighting plant, driven by steam power, for the supply from a Central Station, of 3,000 incandescent lamps of 16-candle-power, with cables laid along the streets, would cost about £20,000.

Mr. Ferguson Bell, of Stafford, states that in their town it would cost £14,500 for a like installation, but he does not include the cost of land in his estimate, details of which estimate are as follows :—

	£
Buildings, which include Engine and Dynamo House, Boiler House, Chimney, &c.	1250
Three 100 horse-power Engines (Steam)	2250
Two 30ft. × 7ft. 6in Lancashire Boilers	1000
Three alternate current Dynamos, complete with Exciters, each capable of supplying 1056 (16 candle-power) Incandescent Lamps	2250
150 Transformers	1500
Charging and Distributing Mains	5000
Regulating and Testing Instruments	250
Contingencies	1000
	£14500

If the number of lights is sufficient, there is also the plan of providing yourself with electric light by means of a complete

plant, driven either by a gas engine or steam engine, on your own premises.

A friend of mine has given me the cost of a complete electric installation, including fittings for 320 incandescent lamps of 16-candle-power each, which has been working for about two years at one of the Banks in London, and is driven by Otto Crossley gas engines :—

Cost of Electric Lighting at a Bank in London, with Accumulators.

Number of Incandescent Lamps = 320 of 16-candle-power.
Capital expended £3000 0 0

Cost of Plant.

	£	s.	d.
Two 9 horse-power Otto Gas Engines and fixing	650	0	0
Two Dynamos	300	0	0
Two sets of Accumulators	1250	0	0
Fitting up the Bank throughout with Wire, Lamps and all accessories, and Architect's charges	800	0	0
	£3000	0	0

Working Expenses.

This building being very dark the lamps have very long hours, say 1800 per annum.

	£	s.	d.
Gas used, 2,000,000 cubic feet @ 2/6 per 1,000	222	0	0
Proportion of Wages of Attendant, who does other work	75	0	0
Oil, Waste and Water	25	0	0
Repairs to Engines and Dynamos, and Depreciation, 10 per cent.	95	0	0
Repairs to Accumulators, and Depreciation, 15 per cent.	187	10	0
Cost of renewals of Incandescent Lamps (each burning 1,000 hours, (*a* 3/9 each)	108	0	0
	712	10	0
Interest on capital, at 10 per cent.	300	0	0
	£1012	10	0

Current of electricity supplied about 35,500 Board of Trade units.

If we analyse the above figures we shall find that—

The cost for generating electricity, including wear and tear and interest on capital is ..... *d.* **5·58** per Board of Trade unit.

	d.		
Interest on Fittings	·56	per Board of Trade unit.	
Cost for renewal of Lamps	·7	,,	,,
The total cost per Board of Trade unit on the complete installation.....	6·84	,,	,,

From these figures it will be seen that if the bank had obtained electricity from a Central Station Electric Lighting Company, at 8d. per unit, the total cost to them would have been—

	d.		
Electricity	8·0	per Board of Trade unit	
Interest on Fittings	·56	,,	,,
Cost for renewal of Lamps	·7	,,	,,
Total.....	9·26	,,	,,

So that by generating electricity on their own premises they save 2·42*d.* per unit, or **£357 19s. 2d.** per annum.

You will observe that in this case accumulators are employed to store the electricity in case of a break-down, so that the electricity can be generated during the daytime with smaller gas engines than would otherwise be required, but the loss of efficiency by the use of accumulators is about 20 per cent., and is a great drawback to this system.

I think it will be found in practice, that the most economical and satisfactory way of producing and supplying electricity to the consumers will be by gas engines on their own premises, or by a system of very small central stations, where a few houses or shops in close proximity can be worked by the direct system of distribution. By this plan you would avoid expensive outlay on buildings, at the same time be advantageously using the existing gas mains, besides being able to dispense with the cost and maintenance of an electrical meter on the premises.

The cost of generating plant on this plan would be as follows:—

Cost of Direct Generating Plant for Electric Lighting

by the use of Gas Engines and Dynamos on the consumers premises, the same being already fitted up with Wires and Lamps.

For 400 Incandescent 16-candle-power Lamps.

	£	s.	d.
One 20 horse-power Gas Engine fixed complete	500	0	0

	£	s.	d.
Dynamo	260	0	0
Slides, Disc Wheel Bearing and Fixing, Switches and Cables in house	140	0	0
Total	£900	0	0

Working Expenses.

Lamps allowed to burn 1800 hours per annum.

	£	s.	d.
Gas used, 2,160,000 cubic feet at 2s. 6d. per 1000	270	0	0
Proportion of Wages of Attendant, who does other work	75	0	0
Oil, Waste, and Water	35	0	0
Repairs to Engine and Dynamos, with Depreciation, 10 per cent	90	0	0
Proportion of Rent, &c.	100	0	0
	570	0	0
Interest on Capital at 10 per cent	90	0	0
	£660	0	0

Current of Electricity supplied, about 43,200 Board of Trade units.

Cost per unit of electricity, 3·66 *d.*

Cost of Direct Generating Plant for Electric Lighting

by the use of Gas Engines and Dynamos on the consumer's premises, the same being already fitted up with Wires and Lamps.

For 50 Incandescent 16-candle-power Lamps.

	£	s.	d.
One 4 horse-power Gas Engine with Dynamo, &c.	275	0	0

Working Expenses.

Lamps allowed to burn 1,800 hours per annum.

	£	s.	d.
Gas used, 270,000 cubic feet @ 2/6 per 1,000	33	15	0
Proportion of Wages of Attendant, who does other work	18	4	0
Oil, Waste and Water	8	0	0
Repairs	6	0	0
Depreciation	13	10	0
Rent	4	0	0
	83	9	0
Interest on capital 10 per cent	27	10	0
	£110	19	0

Current of Electricity supplied about 5,400 Board of Trade units.

Cost per unit of Electricity = 4·93. *d.*

By this plan electricity can be supplied, as shewn by these examples, at prices varying from 3·66d. to 4·93d. per Board of Trade unit, according to the size of the installation, inclusive of working expenses, repairs, depreciation, and interest on capital. The usual charge by the London Electrical Companies, whose supply is generated for large districts in large stations driven by steam power, is 8d. per unit; shewing a saving of 4·34d. and 3·07d. per unit respectively in favour of the gas engine scheme. To explain how the charge for working by gas is obtained, we first take the quantity of gas required per indicated horse power per hour at 20 cubic feet; with this amount of gas a maximum of 8 lamps of 16-candle-power each can be maintained per hour, and by allowing a little extra for irregularities, and taking 50 cubic feet of gas to produce one Board of Trade unit, the gas will cost 1½d., to which must be added the other figures in the table of working expenses just read.

The reason why electricity can be distributed to consumers by gas engines cheaper than from a large central station, is because we can dispense with the very expensive cables for distributing the electricity (which in most cases take one third of the capital employed), and the further expenses for renewal after they have been in use for a time. It is stated that Edison's cables in Berlin only last 3 years. These cables cost £90,000 for 36,000 lamps of 16 candle power and 144 arc lamps. From these facts it is quite clear that the interest on the first cost, and maintenance and renewals of distributing plant alone, will be more than the cost of gas delivered on the consumers premises from the existing mains.

I think the Corporation of Manchester are quite right in obtaining a provisional order from the Board of Trade for supplying the electric light, for which they can put up plant themselves, or get other parties to supply them. In my opinion they ought not to put down an electric lighting station unless it is first ascertained that there will be sufficient consumers who will use electricity enough to secure a profit, after allowing for interest, repairs, maintenance, sinking fund, and other expenses. At the present time they have excellent distributing plant for the purpose in the existing gas mains, which, by the aid of gas engines (which could be placed in a cellar, outbuilding, or any

other position) would supply a power available at any time, requiring no constant attention and causing no smoke nuisance. These gas engines are already extensively used, Messrs. Crossley Brothers having sold 550 for this purpose.

Some might object to this outlay, and where this is a stumbling block, I strongly advise corporations and companies to throw a little more enterprise into their undertakings, and provide and let out on hire gas engines and dynamos in the same manner as they let out cookers and gas stoves. In some cases it might be advisable to sell the gas at a cheaper rate for electric lighting and heating purposes.

I have not referred much either to the Arc or Incandescent Lamps for public lighting, because it has been proved over and over again that neither of these lights can possibly compare with Bray's and other improved burners and lanterns, such as you see in our city, either for cost or efficiency in lighting power.

In many cases where arc lights of high power were employed on out-door work, they have been superseded by the Lucigen and Wells' Patent Portable Lights, the latter being supplied with Wells' oil, or refined gas tar. This is a very cheap and useful light, 250 of them are in use on the Ship Canal, and I learn that 1000 have been sold since October.

It must not be forgotten that in nearly all cases both gas and electric light are obtained from the energy contained in coal, and that gas companies and corporations, who own gas works, can produce as much light direct from the gas made from a ton of coal (if properly applied) as can be obtained from a ton of coal by any other means, besides having the resulting coke, tar, and ammoniacal liquor to dispose of. So, as far as I can judge, gas must remain by far the more economical of the two methods of lighting.

Water Gas is a subject which has been brought very prominently before the public during the last year or two, more for the purpose of floating speculative Companies, perhaps, than because of any real novelty; for at least 30 years have elapsed since it was new to English gas engineers, and many have been the trials of variations of the same principle, owing to the extreme simplicity of the apparatus and the large amount of work that can be done on a small area of land; but the question of ultimate

economy has often prevented the success of schemes, which otherwise were satisfactory. At the present moment I am referring more particularly to the use of water gas for general lighting purposes, as there are many examples in England of its admirable qualities as a heating agent for certain processes.

Water gas is generally made in the following way: a vertical plate-iron vessel lined with firebrick, like a short foundry cupola, and provided with a cover at the top and clinkering doors at the bottom, has an outlet near the top for producer gas, and another near the bottom for water gas, both these outlets having valves which can be closed at pleasure, and they are generally so connected by gear or levers that when one is open the other must be closed. A pipe near the top is provided, through which steam can be passed, and another pipe at the bottom is connected with an air blast, obtained either from a fan or a steam jet, and both the steam and air valves are coupled to the gearing working the gas valves; so that the water gas valve and the steam are open at the same time, and the air and producer valves closed, and *vice versa*. The fuel, which may be coal, coke, or anthracite, is then placed in the cupola—commonly called the generator—and a light is applied; then the air blast is turned on until the whole mass of fuel is at a glowing heat. While this is taking place a quantity of carbonic oxide gas, mixed with nitrogen and a little hydrocarbon, is produced, and passed away through the producer-gas valve to be used under boilers, or for any other purpose requiring fuel; but it is of very poor quality. Then the air blast is shut off and the producer-gas valve closed, and by the same operation the steam is turned on to the top of the glowing fuel, the water-gas valve being opened by the same movement, as previously described. The steam then forces its way down through the fuel, and gets split up by chemical action of the fuel into oxygen and hydrogen; the latter passes through without material change, but the oxygen is taken up by the carbon, forming at first carbonic acid, which, in passing down through the glowing carbon, takes up one atom more of carbon, and becomes de-oxidised into carbonic oxide, which then passes, mixed with the hydrogen, out through the water-gas valve into purifying plant, and very often through carburetting processes,

if for lighting purposes, and finally into the gasholder.

This process goes on until the heat absorbed by the chemical processes taking place so far reduces the temperature of the carbon that it is no longer able to split up the steam into oxygen and hydrogen. Then the steam and gas valves are closed, and the blast turned on again until a suitable temperature is again regained.

The air blast is generally kept on for 10 or 12 minutes, and the steam about 4 minutes, but the time varies somewhat with the size of the generator. One great drawback to the process is the time spent in producing the necessary heat, and the large volume of producer gas of very poor quality thereby generated.

In America, where the water-gas system has reached its highest development, the gas is often produced from generators upon a large scale on the same works as ordinary coal gas. In some places in England, where water-gas is used for heating, the producer-gas is a great nuisance and source of loss.

There is a great difference between the circumstances of the production of water-gas as a lighting agent in America, and its production here : for in America the petroleum oil used to invest the gas with lighting properties is easily obtained at a very low price, and the price of coal-gas is much higher than in England, so there is a greater margin between the two kinds than is the case here.

As a heating agent water-gas is very valuable where a very high flame-temperature is desirable, as the theoretical temperature is about 5000° Fah., while that of coal-gas is about 2500° Fah.

I wish to point out that mistaken notions are frequently held by persons not specially interested in the question, though of thoroughly scientific education, as regards the heating value of ordinary coal gas compared with the so called "heating gas." The fact is that, roughly speaking, the better the lighting qualities of a gas the greater its heating value, and a far greater number of heat units are contained in a pound of ordinary coal gas than in the same weight of the best "heating gas" yet produced—the name "heating gas" should be taken to be simply

a name to distinguish it from a gas which has not only greater heating value, but a lighting value as well.

Besides the method of rendering water-gas valuable as a lighting agent by means of carburetting it, there is another way by which it can be used in its original state. I refer to the use of a magnesia comb, which is rendered incandescent by the heat imparted by the combustion of water-gas, and throws out a very nice white light; but the combs require frequent renewal and are very fragile. English engineers who have visited America to inspect the water-gas processes in use, think that it might be an advantage to adopt the same system to a certain extent in England, if petroleum can be bought at a sufficiently low price to make the gas a commercial success. I think this is very questionable.

I hope, gentlemen, that I have not wearied you. It is very difficult in an address of this kind to enter in detail into many of the important matters treated upon. I have endeavoured to give chapter and verse from actual experiment and experience, where it has been possible to institute comparisons. The only way to arrive at the truth is to thoroughly ventilate these important matters, which is the special object of our Association, and if I have in any way gratified you, or thrown any light upon the subjects under review, I shall have reaped my reward.

VOTE OF THANKS.

Mr. S. Dixon regretted that the etiquette of the Association's proceedings did not allow of any discussion on the address, since it contained so many interesting and debateable points; at the same time they were not prevented from giving their President a hearty vote of thanks, and he therefore formally proposed:

> That the best thanks of the members be given to Mr. West for his very able and comprehensive address.

Mr. Alderman W. H. Bailey seconded the motion, and after commenting on the impartial manner in which the

subjects in the address had been presented to them, briefly alluded to the benefits which the labour and researches of the late Dr. Joule had conferred upon engineers, and concluded with an urgent appeal to the members to support in every way the movement now in progress for the establishment of a suitable memorial to that eminent scientist.

The motion was carried with acclamation.

The President. in acknowledging the vote, said nothing would have given him greater pleasure than to have had his remarks criticised, but he hoped on some other occasion to afford them the opportunity of discussing the relative merits of electricity and gas.

The Evaporation of Lancashire Boilers.

A PAPER

READ BY

Mr. M. LONGRIDGE, M.A., M.Inst.C.E.,

On 25th JANUARY, 1890,

AT THE GRAND HOTEL, MANCHESTER,

MR. JOHN WEST, M.Inst.C.E., President,

IN THE CHAIR.

MANCHESTER:
HERALD & WALKER, PRINTERS, BACK POOL FOLD, CHAPEL WALKS.
1890.

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THE EVAPORATION OF LANCASHIRE BOILERS.

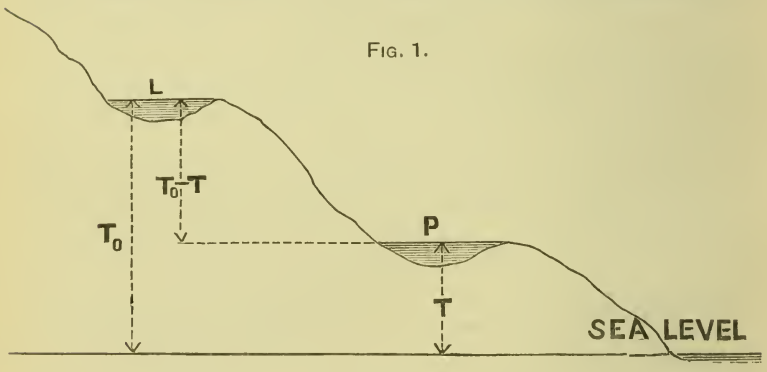
The Lancashire Boiler is such a common object in this part of the world that it is difficult to avoid the feeling that some sort of apology is required for venturing to ask a Society of Manchester Engineers to spend an evening in considering it, for it would almost seem as if everything that could be said about it must have been said already. In one sense this is true. As a structure the boiler has been so minutely studied and described that if the diameter and working pressure were given, none of us would find much difficulty in drawing a specification from which a perfectly safe boiler could be made, and if the factor of safety were also given I venture to say that, with the exception perhaps of some little disagreement about internal flues, the specifications would be practically identical.

But if besides fulfilling conditions as to strength, the boiler were required to evaporate a given quantity of water in a given time and from a given quantity of coal, I fear that unanimity would vanish, that speculation rather than calculation would guide our pens, and that the result would be *quot homines tot sententiæ.* I, at least, have no hesitation in confessing that the problem would be very difficult to solve, and my object in bringing this paper before you is to explain how I have tried to solve it, and to learn what you have done in similar cases.

In 1882 a lecture was given at the Institute of Civil Engineers in London, by Mr. William Anderson, "On the generation of steam and the thermo-dynamic problems involved." It is a lecture well worth reading, and it contains an illustration which I am sure Mr. Anderson will not object to my quoting, with one or two verbal alterations, as an introduction to my argument. He drew a picture (like fig. 1, page 28) representing the section of a hillside. "Some distance up there is a lake L fed by streams "running down from a still higher level. Lower down on the

"slope is a mill pond P, the tail race from which falls into the "sea. At the mill pond is established a turbine, driven by "water descending from the lake through a pipe. Datum or "zero is the sea level. The level of the lake is T_0, and of the "mill pond T. W is the volume of water falling through the "turbine per minute, σ the weight of one cubic foot. The sea "level is the lowest level to which the water can possibly fall, "hence its greatest potential energy, that of its position in "the lake, is $W \sigma T_0$. The water is working between the

FIG. 1.



"absolute levels T_0 and T, hence the maximum effect to be "expected is

$$\text{"}W \sigma T_0 \left(\frac{T_0 - T}{T_0}\right) = W \sigma (T_0 - T)\text{"}$$

If for "hillside" we substitute "boiler flue," for "lake" "furnace," for $W \sigma$, the weight multiplied by the specific heat, or the heat capacity of the gases in the furnace, for T_0 and T, the absolute temperatures of the gases in the furnace, and at the end of the flue, and for the sea level, the zero of absolute temperature, then $W \sigma T_0$ will represent the absolute energy of the heat generated in the furnace, and

$$W \sigma T_0 \left(\frac{T_0 - T}{T_0}\right) = W \sigma (T_0 - T)$$

the maximum proportion of $W \sigma T_0$, which we can by any possibility utilise so long as the initial and final temperatures of the gases are T_0 and T.

Thus, as the water in the lake possesses energy in virtue of its height, so does the fuel in the furnace possess energy in virtue of its temperature. As on the hillside the energy of the water in the lake cannot become active without a fall of level, so in the boiler the energy of the heat in the furnace cannot be utilised without a fall in temperature. And as in the waterfall the work done by the turbine is proportional to the change of level, so in the heat engine is the work done by the heating surface proportional to the change of temperature.

Therefore if W be the weight of gases per lb. of coal, σ their mean specific heat at constant pressure, T_0 and T the initial and final temperatures of the gases (whether measured from absolute zero or any other point is immaterial), the heat available for evaporating water cannot exceed $W\sigma\ (T_0 - T)$ thermal units per lb. of coal.

So far we have dealt exclusively with quantity. We must now consider time, or settle the rate at which the heat $W\sigma\ (T_0 - T)$ can be transferred from the gases to the water. This is really the question with which this paper is concerned, and it is a question of very considerable difficulty, and in my opinion well worth your consideration. The way in which I have tried to answer it is this: first to obtain a general approximate formula connecting the different variables involved, and then to determine by experiment the constants and corrections required to make the formula available for numerical calculation under practical conditions.

If S = the number of square feet of heating surface per lb. of coal burnt per hour.

W = the weight of gases per lb. of coal.

σ = the mean specific heat of the gases under constant pressure.

T_0 = the temperature of the gases in the furnace.

T = the temperature after passing over surface S.

t = the temperature of the water in the boiler.

m = the number of units of heat transmitted through the plates per square foot of surface per hour, and per degree difference of temperature.

Then considering m as constant and the rate of transmission proportional to the difference of temperature, the heat transmitted by an element of surface δS is $m\,(T-t)\,\delta S$: and the heat lost by the gases in passing over the the surface δS is $-W\sigma\,\delta T$. Equating these two quantities we have

$$m\,(T-t)\,\delta S = -W\sigma\,\delta T$$

or

$$-\frac{m}{W\sigma}\delta S=\frac{\delta T}{T-t}$$

and integrating

$$-\frac{m}{W\sigma}S=\log._{\epsilon}(T-t)+\text{constant.}$$

when $T=T_0$, $S=0$.

$$\therefore\ 0=\log_{\epsilon}(T_0-t)+\text{constant}$$

and, constant $=-\log_{\epsilon}(T_0-t)$

$$\text{whence } -\frac{mS}{W\sigma}=\log._{\epsilon}(T-t)-\log._{\epsilon}(T_0-t)$$

or taking common logarithms and transposing

$$m=2{\cdot}3\times\frac{W\sigma}{S}\left\{\log.\,(T_0-t)-\log.\,(T-t)\right\} \qquad (1)$$

By means of this equation and a sufficient number of experimental observations of the values of the symbols in the right hand member, I hoped to determine the general value of the constant m, and this once done to use the formula

$$\log.\,(T-t)=\log.\,(T_0-t)-\frac{mS}{2{\cdot}3\,W\sigma} \qquad (2)$$

to calculate the final temperature T of the gases for any proposed case where the working conditions defining $W\sigma$, T_0 and t were given, and then to calculate the probable evaporation in the following way:—

Having found T, the heat lost by the gases is $W\sigma\,(T_0-T)$. Part of this heat is expended by transmission through the brickwork and by radiation, and partly in heating air drawn into the flues between the brickwork and the boiler. Call this heat R. The remainder is transmitted to the water in the boiler. If t_0 be the temperature of the feed, w the number of lbs. of water evaporated per lb. of coal, then the heat transmitted to the water is $w\,(1114+{\cdot}305t-t_0)$ thermal units per lb. of coal. Equating this to $W\sigma\,(T_0-T)-R$, the number of lbs. of water evaporated per lb. of coal will be

$$w = \frac{W\sigma\,(T_o - T) - R}{1114 + \cdot 305t - t_o} \quad . \qquad (3)$$

It will be noticed that in constructing the general equation of transmission (2) I have treated m and t as constant, and have assumed that all the gas passes over the whole of the heating surface.

Now as regards m this treatment is certainly incorrect. Instead of being constant m is a function of T_o, T, t, of the condition of the plates in respect of soot and scale, and of the rapidity of circulation of the water and gas currents, for both water and gas are such bad conductors that unless the layers of heated water and cooled gas next the plates are rapidly displaced, the transmission is materially reduced. The mathematical expression of this function and its introduction into the differential equation, however, seemed so utterly impracticable, that there was no alternative but to adopt Newton's hypothesis, and treat m as constant in the integration, afterwards providing for such variations of this constant as experiment might suggest by a table of values or an empyrical formula.

As regards t, the difference in the temperature of the water in contact with the different parts of the heating surface of Lancashire Boilers is so small, that no material error can occur in treating it as constant and equal to that due to the steam pressure.

The error involved in the third assumption is also small, and the variation of the error smaller still, and it is this variation only which affects the coefficient m so long as this coefficient is applied to one type of boiler. Strictly speaking, the evaporation from the furnace plates should be calculated separately, and the formula (2) applied only to the part of the boiler beyond the bridge. But with any ordinary extent of heating surface, the results of the two methods differ by so little, that it is not worth while complicating the subject by the addition of another calculation.

Having made these necessary observations, I must now explain the way in which I have found the values of $W\sigma$, S, T_o, T, and t, which are required in order to determine m from

equation (2), and I think I can do this best by taking a concrete case; for this purpose I have selected one of my own experiments with two Lancashire Boilers, 7ft. diameter by 30ft. long, hand-fired. This experiment is fully described in my annual report for the year 1888, and I will only give such particulars here as are necessary to the comprehension of the question before us.

The result of the experiment expressed in the form of a debtor and creditor account were as follows :—

BOILERS.

		Thermal units.
Dr.	To calorific value of 1lb. dry coal	13363
	To heat contained in 1lb. coal.....	22
	To heat contained in air, 14·79lbs. entering furnace at 54°	179
	To heat contained in moisture held by air.....	2
	Total.....	13566
Cr.	By heat required to raise 9·819lbs water from 206° to 326°, and to evaporate it into steam containing three per cent. of moisture	9626
	Heat carried off in waste gases.	
	9·146lbs. products of combustion at 648°	1606
	5·618lbs. unburnt air, 0·135lbs. vapour and 0·16lbs. steam, arising from evaporation of water mixed with the coal	914
		2520
	Heat absorbed in evaporating ·016lbs. water mixed with coal	18
	Heat lost by imperfect combustion.....	0
	Calorific value of ·0395lbs. of unburnt carbon in ashes	575
	Heat lost in clearing fires.....	45
	Remainder, including heat lost by radiation and unaccounted for	782
	Total.....	13665

The heating surface of the boilers was 1,810 square feet, excluding the lower halves of the furnaces below the bars as is usually done, though why they should be excluded I do not quite understand, as they certainly receive heat radiated from the grates, though no doubt the quantity is very small.

The weight of dry coal burnt per hour was 1,073lbs.

The weights, specific heats, and heat capacities of the waste gases are given below:—

		W lbs.		σ specific heat.		W σ = Heat capacity.	
Products of combustion	Carbonic acid	2·721	×	0·216	=	0·588	
	Nitrogen	6·870	×	0·244	=	1·676	
	Steam from combustion of hydrogen	0·445	×	0·481	=	0·214	
							2·478
Air in excess and water	Air	5·618	×	0·238		1·337	
	Vapour in air	0·135	×	0·481	=	0·065	
	Steam from water mixed with coal	0·016	×	0·481	=	0·008	
							1·410
							3·888

The value of S is found by dividing the heating surface by the weight of dry coal burnt per hour, and is in this case 1·69.

The value of W σ is given above, namely 3·888.

The value of T_0 must be obtained by calculation, since we have no reliable method of observing it directly. The calorific value of the coal was 13,363 thermal units, but this value was reduced by various losses in the furnace, as shown in the balance sheet, namely: —

18 units absorbed in evaporating the water mixed with the coal.

575 units, the equivalent of ·0395lbs. of unburnt carbon mixed with the ashes.

45 units lost in the hot ashes and clinkers, altogether 638 units, which being deducted from the calorific value of the coal leaves 12,725 units available for raising the temperature of the gases.

The heat capacity of the gases being 3 888, these 12,725 units would heat the gases $12725 \div 3{\cdot}888 = 3273°$, and as the temperature of the air entering the furnaces was 54°, the temperature of the fire was 3327°, and this I take as the value of T_0.

The values of T and t were obtained directly by observation; they were 648° and 326° respectively.

Substituting these numbers in the right hand member of equation 2, we have

$$m = 2{\cdot}3 \times \frac{3{\cdot}888}{1{\cdot}69} \left\{ \log.\ (3273 - 326) - \log.\ (648 - 326) \right\}$$

$= 5{\cdot}13$ thermal units.

From this slight sketch, you will see that the determination of m depends upon a knowledge of a number of other quantities, the accurate evaluation of some of which is very difficult. To begin with, it is by no means easy to learn the calorific value of the coal itself. First, there is the exceeding difficulty of selecting an average sample for analysis and testing, and secondly, the calorific values calculated from analyses, hardly ever agree with those found from calorimetric tests. In my work I have been forced to content myself with one analysis of each coal I have used, but when using the same coal for several days I have made generally three calorimetric tests for each day: unfortunately, I have found that the three tests of one day, though agreeing among themselves, have not in general agreed with those of other days, although the coal was said to be supplied from the same seam and pit. I have found as much as 1000 thermal units difference in different loads of what was supposed to be the same coal. In general, I have taken the analysis (as was necessary) as the basis for calculating the volumes and weights of the chimney gases, but have relied upon the calorimetric tests for fixing the calorific value of the fuel. (Perhaps I may here suggest that in making tests with Thompson's calorimeter, the value obtained must be reduced by the heat liberated by the condensation of the steam arising from the combustion of the hydrogen in the coal, for when the coal is burnt in a boiler furnace this steam is not condensed, and does not give up its latent heat as it does to the water in the calorimeter. This correction is frequently overlooked; with Lancashire coals it generally lies between 400 and 500 units.)

Secondly, there is the difficulty of determining the amount of the losses in the furnace, which have to be deducted from the calorific value of the coal, before the quantity of heat available for the calculation of T_0 can be fixed.

The most important of these are: the heat equivalents of the unburnt carbon, which is lost among the ashes, and of combustible gases, passing off unburnt.

Without making an analysis of the ashes, which I have been unable to undertake, the only means of estimating the quantity of unburnt carbon is to deduct the percentage of ash given by the coal analysis from the percentage actually thrown away;

a method which can only give correct results if the percentage given by the analysis of the single sample analysed be the same as the percentage in the bulk of the coal burnt.

The amount of the loss due to imperfect combustion is also difficult to ascertain outside a laboratory. It is frequently asserted that combustible gases cannot exist in company with a large excess of air. This I think is a mistake. It is true it is often difficult to find carbonic oxide, while carbon vapour and free hydrogen entirely elude the snares of the apparatus ordinarily used for outdoor work. My experience, however, is, that with care and patience, carbonic oxide can very frequently be found in small proportions, while as regards free hydrogen the experiments of Scheurer Kestner* seem to show that, in general, about 20 per cent. of the hydrogen in coal escapes unburnt whether the supply of air be great or small.

If these experiments be relied on, the losses in the furnace will exceed those found in the balance sheets of trials, while the remainders usually ascribed to radiation and heat unaccounted for will be diminished. Hence the probability is that the losses in the furnace have been under valued, and the temperature T_o over stated somewhat in my experiments.

Lastly, there is great uncertainty about the temperature of the waste gases if they exceed 600°, the maximum temperature for which a mercury thermometer can be used. I have tried Casartelli's, Schaeffer's, and Murrie's pyrometers, and found them altogether unreliable, hence in all the experiments in table I except those lettered A to E, I have had to correct the observed final temperature of the gases. This I have done by assuming a loss of 700 units from radiation and communication of heat to air drawn into the flues between the boiler and the brick-work, adding this to the heat absorbed by the water, and dividing the sum by the heat capacity of the gases, and then checking the results by the work done in the economisers, and the heat carried up the chimney where the temperatures were measurable by a mercury thermometer, and though I cannot hope to have arrived at accurate results, I think the figures are not far from the truth.

* Recherches sur la combustion de la houille par A.M. Scheurer Kestner Mulhouse 1868.

In experiments D and E, the pyrometer was found to agree with a mercury thermometer up to 550, and therefore the observed temperatures of the waste gases are probably not far wrong, and are given as they were observed. Experiment B was made in Vienna, and I have no information about the pyrometer used. In experiment A the final temperature was low enough to be measured by a thermometer. The temperatures in table II. were all taken with a thermometer and are correct, except perhaps those in L and M.

With such difficulties to overcome, it is not surprising that the determinations of m which I have hitherto made, should be somewhat variable. They are given in the following tables, I. and II., and cannot be considered as more than near approximations.

The figures in table I. refer to Lancashire Boilers, those in table II. to a combination of a Cornish Boiler with a pipular boiler, but inasmuch as the furnace was internal, and the greater part of the evaporation done in the Cornish part, I think the value of m obtained from it are worth producing in addition to those shown in table I. (See opposite page.)

Referring to these tables you will see that in experiment A the value of m is very low; the reason I think is that the temperatures of the gases was reduced so much, as to deposit a great quantity of soot upon the latter end of the large heating surface, and thus, the effective heating surface per lb. of coal burnt, was really less than the value ascribed to S. If this ineffective surface were not counted, the value of S would be reduced and that of m increased.

In C also m has a low value, but this is fully accounted for by the fact that the boilers were old ones, fed with very dirty water, and coated internally with thick scale. The figures in column D were obtained from the same two boilers as those in column E, and it is likely that the different values of m in the two experiments is due to the different conditions under which the boilers worked. The difference between T_0 and the observed value of T being produced in part by the absorption of heat by air entering the flues between the boiler and the brickwork, it is natural that T should be lower with the strong draught, like that indicated by the value of $W\sigma$ in D, than with

TABLE I.

		A	B	C	D	E	F	G	H	I	J
1	S	3·98	1·64	1·62	1·59	1·69	1·41	1·42	1·44	1·45	1·43
2	Wσ	5·979	8·734	3·987	5·302	3·888	6·61	6·55	5·66	5·36	6·20
3	Value of Coal net.	14311	12450	11424	12871	12725	11239	11586	12026	12361	11282
4	T_0	2466	1518	2933	2482	3327	1756	1826	2170	2352	1866
5	T	399	691	750	700	648	743	782	700	730	703
6	t	298	304	322	327	326	308	308	326	326	316
7	m	4·60	5·97	4·41	5·84	5·13	5·61	5.36	6·28	5·97	6·39

TABLE II.

		L	M	N	O	P	Q	R	S	T	
1	S	1·9	2·03	2·48	2·98	2·98	2·70	3·36	3·05	3·45	
2	Wσ	4·788	4·479	4.799	4·527	4·268	3·924	4·893	4·529	4·804	
3	Value of Coal net.	12547	12610	13159	12705	12697	12482	12623	13289	13200	
4	T_0	2670	2858	2785	2843	3014	3191	2618	2967	2790	
5	T	405	428	440	381	394	430	410	419	394	
6	t	307	307	307	307	307	307	305	307	307	
7	m	8	6·72	5·65	5·36	4·92	4·60	4·50	4·71	4·70	

the weak draught shown in E. But the formula for calculating m is based on the supposition that the difference $T_o - T$ is produced by absorption of heat by the water alone, hence the value of m determined by it will always be higher with a strong draught or leaky flue than with a weak one and air-tight flues, and the actual co-efficient of transmission rather less than the calculated. The high coefficients in F, G, H, I, J are due partly to strong draught, and partly to the boilers being very clean.

The high values in L and M are inexplicable, except on the supposition, that the thermometer was effected by a current of cold air, which entered at the damperhole and at a crack in the brickwork, or that the loss by imperfect combustion was greater than that calculated from my analysis of the gases, or that the net heating value of the coal and the temperature T_o were over estimated. The last seems the most likely, for the coal had been lying out of doors some time, and the outside of the heap was used for trial L, and the part near the outside for trial M.

The low values in $P - T$ are no doubt due, as in A, to the effective surface of the boiler being less than the actual surface, owing to deposition of soot upon the hinder parts.

On the whole I am disposed to think that the following values of m may be adopted till further experience throw more light upon the subject.

TABLE III.

	S =	1	1·5	2	3	4
For very clean boilers ..	m =	6·5	5·9	5·5	4·9	4·6
For fairly clean boilers..	m =	6	5·4	5·1	4·6	4·3
For rather dirty boilers..	m =	5·5	4·9	4·6	4·2	4·1

Intermediate values of m may be obtained by the formula

$$m_n = m_1 \div \sqrt[4]{S}$$

of course this formula has no rational foundation, it is only a convenient expression for substitution in the general formula when S is the unknown quantity.

I now return to the problem with which I started, namely, that of designing a Lancashire Boiler to evaporate a given

quantity of water at a given rate. If the calorific value of the coal and the value of $W\sigma$ be given, T_o can be calculated and T found, and this once done, the rest is easy. But as these quantities are generally unknown, the engineer will have to fix them arbitarily, and therefore ought to know the limits within which they usually lie.

As regards the calorific value of Lancashire coals, my experience is that it varies from 12,000 units to 14,000 units, and that ordinarily good mill coal, whether slack or burgy, has generally a value of about 13,500 units, and contains according to analysis about 78 per cent. of carbon and between 4 and 5 per cent. of hydrogen.

The losses in the furnace may usually be taken between 500 units and 1000 units per lb. of coal, thus reducing the calorific value from which T_o must be calculated to about 12,750 units for good coal.

These losses are generally rather greater with slack than with burgy, owing to mechanical difficulties; for the same reason they are likely to be greater with bad coal than with good, for instance, with coal worth only 12,000 units, the value in the furnace would probably not be more than 10,800 or 11,000 units.

The value of $W\sigma$ depends of course upon the weight of air which passes through the flues per lb. of coal.

It is generally assumed that $12\frac{1}{2}$lbs. of air are required to burn 1lb. of coal in theory, and about 18lbs in practice. But this is only true for carbon, not for coal. As a matter of fact good Lancashire coals require about 10lbs. of air in theory, and with careful stoking, about 15 to 16lbs. of air in practice. In such cases the value of $W\sigma$ will be about 4·5, but in designing a boiler it will be better to take $W\sigma$ at 4·7 for good coal. Of course $W\sigma$ can be increased to almost anything by having a roaring draught such as some firemen delight in. Several such instances are noticeable in table I.

And lastly, as to R, the heat lost by radiation and air leakage into the flues. Very few direct experiments have been made to determine R. It is generally found by difference, and thus includes all errors of observation. As far as I can judge with single Lancashire Boilers, R ought to be between 1000 and 700 units, and with groups of boilers between 700 and 400 units, per lb. of coal.

We can now proceed to the solution of our problem. Suppose it be required to evaporate 5000lbs. of water per hour, under a pressure of 100lbs. per sq. inch. (115lbs. absolute) from feed water at 100°, and at the rate of 9lbs. of water per lb. of coal. The heat required to evaporate 1lb. of water under these conditions is $1114 + \cdot 305 \times 338 - 100 = 1117$ thermal units, therefore, the heat transmitted through the plates from each lb. of coal burnt must be $9 \times 1117 = 10{,}053$ thermal units, to which must be added, say, 700 units for radiation, &c., making in all 10,753 thermal units.

Assuming the coal to have a calorific value of 13,500 units, or 12,750 units after deducting losses in the furnaces, the air to be at 60° and the value of $W\sigma$ to be 4·7, then the value of T_0 will be

$$\frac{12750}{4 \cdot 7} + 60° = 2770°$$

and that of T is given by (3), viz., $4 \cdot 7\ (2770 - T) = 10053 + 700$, whence $T = 482°$.

What heating surface is required to reduce the temperature of the gases to 482°? The answer is given by equation (2), viz.:

$$S = 2 \cdot 3\ \frac{W\sigma}{m}\ \left\{\text{log. } (T_0 - t) - \text{log. } T - t)\right\}$$

Taking the value of m from the second line of table III., refering to fairly clean boilers, viz., $6 \div \sqrt[4]{S}$ and $t = 338$, the temperature of steam at 100lbs. pressure, we have

$$S = 2 \cdot 3 \times \frac{4.7\sqrt[4]{S}}{6}\ \left\{\text{log. } 2432 - \text{log. } 144\right\}$$

or $$S^{\frac{3}{4}} = 1 \cdot 8 \times (3 \cdot 38596 - 2 \cdot 15836) = 2 \cdot 2086$$

The 4th root of S^3 may be extracted with the aid of a table of squares and cubes, by taking the square root of 2·2086, then the square root of that square root, and finally the cube of the result, or more conveniently by a table of logarithms, thus

$$\tfrac{3}{4} \text{ log. } S = \text{log. } 2 \cdot 2086$$

or $$\text{log. } S = \tfrac{4}{3} \times 0 \cdot 34312 = 0 \cdot 45748$$

whence $S = 2 \cdot 87$ sq. ft. per lb. of coal.

Now the coal to be burnt per hour is $5000 \div 9 = 556$lbs., therefore the heating surface required is $2 \cdot 87 \times 556 = 1596$ sq. ft.

How many boilers shall we use?

This depends upon the area of fire grate required. Well, my experience upon the point is this, that it is difficult to burn less than about 16lbs. or more than about 21lbs. of coal per sq. ft. of grate in Lancashire Boilers, without considerable excess of air.

Having to burn 556lbs. of coal per hour therefore, the total grate area should not be less than 26·5 sq. ft., or more than 33·5 sq. ft. Moreover, the length of each grate must not exceed 6ft., and should not by preference be less than 3ft. 6in.

The best way of fulfilling these conditions would probably be to have two Lancashire Boilers, 7ft. diameter by 27ft. long, with internal flues, 2ft. 8in. diameter, and grates, 3ft. 6in. long, set low in the furnaces, especially at the back ends, in order to reduce the mean width to about 2ft. 5in. In order to facilitate these kind of calculations I have drawn up the following table IV. for pressure of 40lbs., 100lbs., and 160lbs., giving the values of S, m, T, t, and $W\sigma\ (T_o - T) - 700$ (=the heat available for evaporation) on the assumption that

The calorific value of the coal	= 13,500	thermal units.
The losses in the furnace	= 750	,,
The heat available in the furnace	= 12,750	,,
Loss by radiation, &c.	= 700	,,
The value of $W\sigma$	= 4·7	
Temperature of air	= 60°	

These figures being taken as representing fair average values of the different quantities, such as an engineer might fairly adopt as a basis for calculation, when without information as to the actual values.

TABLE IV.

S	1	1·25	1·5	2	3	4
m	6	5·7	5·4	5·1	4·6	4·3
Steam Pressure, 40lbs. t = 287°						
T ..... deg. fah.	978	831	729	570	418	351
$W\sigma\ (T_o - T) - 700$ th. units	7721	8414	8893	9640	10355	10670
Steam Pressure, 100lbs. t 338°						
T ..... deg. fah.	1015	871	771	615	466	400
$W\sigma\ (T_o - T) - 700$ th. units	7549	8226	8696	9429	10129	10437
Steam Pressure, 160lbs. t = 371°						
T ..... deg. fah.	1039	897	808	644	498	432
$W\sigma\ (T_o - T) - 700$ th. units.	7436	8103	8521	9292	9978	10289

and from the figures I have plotted the three curves, figures 2, 3, 4 ; the abscissæ being the values of S, and the ordinates the corresponding values of T., and of $W\sigma\ (T_o - T) - 700$.

The use of these curves will be easily understood from one or two examples.

1. What extent of heating surface is required to obtain 8lbs. of steam per hour per lb. of coal at 100lbs. pressure from feed water at 150° ?

Each lb. of steam will absorb $1217 - 150 = 1067$ thermal units; therefore 8lbs. of steam will absorb $8 \times 1067 = 8536$ thermal units. The value of $W\sigma\ (T_o - T) - 700$ is therefore 8536. Take diagram, fig. 3, set off 8536 on the scale at the right side, through 8536 draw a horizontal line, and from the point where this horizontal line cuts the curve, $W\sigma\ (T_o - T) - 700$ drop a perpendicular to the base line of the diagram. This perpendicular will cut the base line at the point $S = 1{\cdot}3$. Therefore 1·3 sq. ft. of heating surface must be provided for each lb. of coal burnt.

2. What will be the temperature of the gases leaving the flues in the last case ?

Through the point where the perpendicular from $S = 1{\cdot}3$ cuts the curve T, draw a horizontal line cutting the scale at the left of the diagram. The point where the horizontal cuts the scale will be the temperature required, in this case about 825°.

3. A boiler is working at 40lb. pressure. It is short and hard fired, having only 1 sq. ft. of heating surface per lb. of coal burnt per hour. The feed is at 60°. How much water will be evaporated per lb. of coal ?

Taking fig. 2 we see that when $S = 1$ the heat available for evaporation, $W\sigma\ (T_o - T) - 700$, is 7750 thermal units. To evaporate 1lb. water from 60° of steam of 40lbs. pressure requires $1201 - 60 = 1141$ thermal units. Therefore the water evaporated per lb. coal will be $7750 \div 1141 = 6{\cdot}78$lbs.

4. What would be gained in evaporation by doubling the heating surface or increasing it to 2 sq. ft. per lb. of coal burnt?

The ordinate from the point $S = 2$ cuts the curve $W\sigma\ (T_o - T) - 700$, at the height 9,700 measured on the right hand scale. Each lb. of coal would therefore transmit 9,700 units

to the water instead of 7750 as in the last case, and the evaporation per lb. of coal would be increased from 6·78lbs. to $9{,}700 \div 1{,}141 = 8{\cdot}5$ lbs.

These examples I hope have made the meaning of the diagrams quite clear and their application easy, so easy that some, I fear, may be tempted to use the curves without ascertaining by a study of the paper, the hypotheses on which they have been constructed, and thus to apply them to cases where these hypotheses do not exist, instead of using the general formula 2 and 3 with proper values for the variables. If any one feel tempted so to do, I warn him that he will do it at his peril, for he will be handling edged tools without sufficient knowledge of their properties and uses to keep his fingers out of mischief.

I have now done my best for the engineer, and will conclude my paper with a few practical hints to boiler owners.

1st. Get your boilers designed for the work they have to do, and not made 7ft. 6in. × 30ft. or 8ft. × 28ft. as the case may be, because it is the fashion to have boilers of these particular dimensions.

2nd. Don't stick to 6ft. grates if a shorter length is required to burn the coal at the rate of from 16 to 21lbs. per hour.

3rd. Reduce your draught as much as the nature of the coal and the smoke inspector will permit. Try and reduce it till the fire is hot enough to melt a piece of steel boiler plate.

4th. Buy your coal dry and keep it dry. Weigh the ashes which come out of the furnaces as well as the coal that goes into them.

5th. Be most careful to stop up air leaks in the brick work and between the brick work and the boiler.

6th. Establish a gasometer for collecting gases from the flues and analyse them for carbonic acid, and try to get 10 or 11 per cent. of that gas in the samples by cutting down the draught. The apparatus and its manipulation are of the simplest character, and the information gained will be of great practical utility, and will often lead to considerable economy.

DISCUSSION.

Mr. Boswell was sure the members and gentlemen present must feel greatly indebted to Mr. Longridge for his very interesting paper, and for the very clear and lucid manner in which he had dealt with such a difficult problem. Mr. Longridge, he said, was too confiding. Engineers did not know as much about boilers as he assumed. No doubt many thought they knew, but such would do well to study closely such admirable lectures as the one before them. For what they did know about boilers, and for the present efficient state of the Lancashire boiler, they were indebted to such gentlemen as Mr. Michael Longridge, Mr. R. B. Longridge, Mr. Fletcher, their late esteemed member Mr. D. Adamson, and a few others in the immediate district, which is now the seat of boiler-making for the world. After all, fashion played an important part in purchasing boilers. Most of them were aware that after the Jubilee Exhibition the size 30ft. × 8ft. was most in vogue, and many of that size had since been made. Not having had Mr. Longridge's paper in hand until that evening it was almost impossible to raise much discussion. They must assume his formula and tables were for fuels of ordinary quality. Would they, however, be serviceable if duff, refuse, or coke breeze were used? Those fuels were now being much used where coal was dear, and special furnaces and forced draughts were being adopted to this end. He had heard of a case where coke breeze costing 1s. 9d., and consumed in a special furnace, evaporated as much water as 5s. worth of coal. With respect to the supply of air, that must be gained by experience with the different qualities of coal used. He believed in having ample chimney capacity, and a good damper to control the draught, but here the advice given before the Association some time ago must be followed, namely, to get intelligent men as stokers, and educate them to their duties, as in every day work the steam user was largely in the hands of his stokers. When experiments were carried out 9lb. or 10lb. of water was evaporated per 1lb. of

coal, but afterwards, when working under ordinary conditions, 8lb. was rarely exceeded. He was pleased to hear Mr. Longridge state that the economical consumption of fuel was between 16lb. and 21lb. per square foot of grate, as this agreed entirely with his experience. Mr. Longridge's advice to steam users was, in his opinion, very good indeed, and they would do well to adopt it. Unfortunately his (Mr. Boswell's) experience was that any advice which increased first cost, however slight, was generally cast aside by the steam user. When a building of any pretentions was to be erected an architect was called in, who enquired what was wanted and what it was to accommodate, the result being a suitable building. If the steam user would call in the boiler expert and say what was required no doubt he would get that which would give him the best return for his money. The steam user does not always know what he requires. As a case in point he might mention that some time ago he was called in to advise. Two boilers, about 20ft. × 6ft. 6in., were struggling on with about 90 I.H.P., and a chimney about 40ft. high, and one square foot of opening at top. As one boiler needed extensive repairs it was decided to lay down one new boiler, 24ft. × 6ft. 6in. He protested against this being done until a new chimney was built, but to no purpose. A new boiler was put in, more coal was used than before, the fireman was always poking and raking, while the draught was so poor that it scarcely drew the flame over the bridge, and push as much as they could they could not consume more than 10lb. to 11lb. of coal per square foot of grate per hour, while with a reasonable draught the boiler would have had its efficiency enormously increased and used much less fuel.

Mr. Alex. Rea said it was difficult to extemporarily discuss an address so full of figures, and follow same with any degree of accuracy, without an opportunity of testing the conclusions arrived at. The value, however, of the paper would be more appreciated when it was printed and issued to the members. At the same time he would have felt more satisfied had the matter been placed in a more practical form. It was no doubt true that mathematical science had done much for engineering, but it must also be admitted that practical science had done

much more. The rules might be called empirical, but it was a *sine qua non* that all theorems and formulæ based on a hypothesis must be tested before they were of any real value. If not trespassing upon good nature he would like to ask Mr. Longridge if he understood him correctly in assuming that a boiler, say 30ft. × 7ft., with a small grate area as described, would be more efficient in proportion to its size than a boiler 30ft. × 8ft. 0in. with a long grate surface as explained.

In reference to the various opinions of steam users, which in many cases were commonly called fads, about boilers, &c., they were not wholly to blame. He was strongly of opinion that engineers themselves were not quite at one on the subject, as the former were a kind of reflex of the latter. They deserved, to say the least, a modicum of commiseration for the blunders made.

In regard to the question of perfect combustion in the boiler furnace, and the quantity of air required per 1lb. of coal, he asked was there any data as to the best speed or velocity of the gases passing through the flues for communicating heat to the water? It was well known that forced draughts as applied to marine boilers gave better results than what was termed the natural draught, and this from a lower grade of coal. He would like to know how this affected a Lancashire boiler. Then there was the question raised by Mr. T. Fletcher, of Warrington, an authority on gases, in what was termed or called the cold zone theory. Did Mr. Longridge think there was anything in this point militating against the Lancashire boiler as an evaporating machine?

Again he would like the lecturer to express an opinion as to the value or otherwise of using corrugated flues and furnaces. Were they more efficient heat communicators than the plain flues as generally made in a modern Lancashire boiler? Did the impact of the heated gases on the corrugations produce any material effect in absorbing the heat generated?

Proceeding, Mr. Rea observed that the question which engineers had to solve was to find out the best method of utilising all the heat produced from the coal, and asked did the Lancashire boiler as made fulfil this natural condition? To his mind there was still room for improvement in this all-important

machine as a steam generator. He was afraid, speaking generally, that there was much more loss of heat in actual practice than the figures given from the experiments made by Mr. Longridge.

His opinion in regard to getting the best effects from a Lancashire boiler was not to press the firing over much. This meant sufficient steam room and a large heating surface for the power required, giving ample time for combustion, so that as the gases were released from the coal they got thoroughly mixed with the heated air and the combustion became almost perfect. To this he would add efficient stoking. Firing, as it was called, might be looked upon as a very simple operation. This was a great mistake, and led to an enormous waste of power annually. It was scientifically producing energy, and ought to be gone about in an intelligent manner, to say the least of it. Stokers should have a good practical training as well as a fair theoretical knowledge of their business. If coal ever reached 40s. per ton this would be brought about, and we should make a far better use of our fuel or latent energy.

Mr. J. E. Hardman asked whether the evaporative duty of 9lb. of water per 1lb. of coal was deducted from ordinary working conditions, as he had been accustomed to receive 8lb. as the average figure.

Mr. E. J. Constantine enquired if Mr. Longridge had had any experience in the application of forced draught to Lancashire boilers.

Mr. Settle asked if greater efficiency accrued from a low velocity of the gases passing through the flue than from a high velocity. In the Lancashire boiler, he remarked, the velocity due to the ordinary natural draught was less than in the locomotive boiler with the blast in the fire-box, which created a powerful draught. In the latter about 100lb. of coal was consumed per square foot of grate per hour, against say a fifth of that quantity in the former boiler fired under ordinary conditions. It seemed to be the prevalent opinion that a low velocity of the gases through the flues conduced to economy by allowing

time for the gaseous currents to give off their heat, and yet the velocity of the gases in a locomotive boiler was much greater than in a Lancashire boiler. The Locomotive boiler, however, was an efficient and fairly economical steam generator.

He might say that Mr. F. Siemens, in a paper he read some time ago before the Iron and Steel Institute, stated as the result of his experiments and experience, that the proper method was to allow the gases to pass through the flues of the boilers unobstructed, since if the heated gases met any body cooler than themselves the flame was extinguished, and the gases consequently passed away more or less unconsumed. Mr. Siemens maintains that the gases and flames should not impinge against the boiler, but should be allowed to give off their heat simply by radiation. By this means it was contended the most economical results were attained.

Now he (Mr. Settle) thought Mr. Siemens' conclusions were against the ordinary ideas on this subject, which were that the heated gases should be caused to impinge against the boiler and thus compelled to give up their heat. Under the above circumstances he would be glad to hear Mr. Longridge say a few words upon the subject, as if Mr. Siemens' contentions were correct it would necessitate a very wide departure in the construction of some Lancashire boilers.

Mr. J. Schofield, while admitting the scientific value of the paper, thought there were several practical points in connection with the subject upon which some opinion might have been expressed. For instance, he asked, what was the best velocity of the draught, the most efficient proportions for the side and bottom flues, and also whether any real advantage accrued from the use of a bridge. Regarding the length for the furnaces, he was of opinion that in an ordinary boiler this could not be too ample, say at least up to 8ft. With a furnace of this length he would only have 6ft. of fire bars, and the remaining 2ft. so arranged that no air could be admitted except by some patent regulator or other apparatus.

He should like an expression of opinion from Mr. Longridge as to the effect of the various thicknesses of plate in a boiler, and the temperature at which the gases should leave it. Personally,

he contended that the temperature of the gases leaving the boiler should not be less than 500°, and if they were issued direct into the atmosphere at that temperature a large amount of heat was being wasted which could be utilised by an economiser. On the contrary, if the temperature of the gases was below the figure stated then as a consequence little work was being done at the back end of the boiler. On these grounds he believed the use of an economiser in every way tended to efficient working.

The President said he was sure they would agree with him that Mr. Longridge's paper was of great value, and he was of opinion that the Association would greatly benefit by such highly scientific contributions. Mr. Longridge had pointed out what we really should get out of our coal, and had reduced it to such a practical formula that engineers might make their own deduction from it. He (Mr. West) thought it was very necessary that they should have those minute theoretical calculations, as it gave them an idea of what was expected of them as engineers. Several of the members seemed to have anticipated that Mr. Longridge would have treated the subject from various standpoints, but he thought the idea was to give them some theoretical and practical notes in connection with the Lancashire boiler, and he was of opinion that the reader of the paper had succeeded in that respect. The calorific value of coal which had been given them coincided more or less with the experiments which he (Mr. West) made many years ago. There was no doubt that Mr. Longridge had had many difficulties to contend with in making the tests consequently upon the inability of getting reliable pyrometers. He had great pleasure in moving :—

> That the very best thanks of the members be given to Mr. M. Longridge for his very valuable and scientific paper.

Mr. Boswell seconded the motion, which was carried by acclamation.

Mr. Longridge, in reply, said he would endeavour to answer the several speakers in the order in which they spoke. In answer to Mr. Boswell, he explained that the numerical examples worked out and the diagrams, only applied to particular conditions which he thought were fair average conditions, but that the formulæ from which the numerical results had been deduced were perfectly general, and were intended to give equally reliable results whether the coal were breeze at 1s. 9d., or Welsh coal at 20s.; whether the air burnt per lb. of coal were 15lbs. or 30lbs., or any other quantity. In reply to Mr. Rea, the author said he had endeavoured to treat the subject in as practical a manner as he knew how. He was perfectly aware that the formulæ which he had given could not be safely used by a youngster, and he did not believe that any formula could be devised which could be so used, but he did think that in the hands of engineers of discretion, who could modify the results of the calculation in accordance with their knowledge and experience, a formula was a guide of great practical utility. At least he found it so, and it was principally the want of such a formula that led him into the cost and trouble of making the experiments from which he had quoted in the paper. He did not set up the formula as infallible, or the constants as exactly correct. The experiments were far too few, and the difficulties far too great to warrant any such conclusion. On the contrary, the paper was merely a first attempt at finding a solution of a problem which he had to deal with in one form or another almost every day.

As to the relative efficiency of boilers 7ft. and 8ft. diameter, he did not think the size of a boiler was very material. In his view, efficiency depended upon the extent of heating surface per lb. of coal burnt, and having determined the extent of surface required to secure a desired rate of evaporation per lb. of coal, he should fix the number of boilers required to give that surface, and consequently the size of the boilers in such a way as to secure sufficient grate area to burn the necessary weight of coal at a rate varying from 16 to 21lbs. per square foot of grate. That was the general principle on which he should go, but of course considerations of cost and local circumstances would always have to be taken account of in applying it.

The quantity of air required for combustion depended very much upon the quality of the coal; with fairly good coal an excess of about 60 per cent. of the weight required by theory would be found sufficient, but with dirty coal which ran upon the bars a larger excess was needed to keep the bars cool.

He had had no experience with forced draught. There could be no doubt that where the natural chimney draught was insufficient to burn very dirty coal, forced draught would lead to considerable economy, simply because it enabled the boiler owner to burn very cheap fuel. It would also enable the boiler owner to extend the heating surface and reduce the temperature of the chimney gases, but he did not think that such a proceeding would be practically economical in England, because the interest on the cost of the extended heating surface would balance the saving in the quantity of heat sent up the chimney. Putting aside the possibility of burning cheaper fuel, he could not see how forced draught could lead to economy, and he did not believe it did. He did not think the cold zone theory was applicable to Lancashire boilers, except, perhaps, where the fire bridges were very high. In such cases it might happen that the flame might be extinguished by contact with the plates. So far as corrugated flues allowed of a larger heating surface being got into a given space, no doubt they were more efficient than plain flues, but he did not think they transmitted any more heat per square foot, and in this sense they were not more efficient. No doubt they could be made thinner than plain flues, but within the limits occurring in practice, he held with Peelet that the rate of transmission through the body of the plates being so much higher than the rate of transmission at the surface, the thickness was immaterial. Mr. Rea had asked him whether he thought the Lancashire boiler was the best boiler for utilising the heat in the coal, and had expressed the opinion that there was still room for improvement. In one sense the Lancashire boiler was certainly not the most efficient boiler. It was a slow working machine, and consequently a large and heavy machine for the work got out of it. As regards the speed of working and size, a locomotive boiler was much more efficient, for the co-efficient m, or rate of transmission per square foot per degree difference of temperature in a locomotive boiler was nearly twice as great

as in the case of the Lancashire boiler, consequently much less surface was required to do a given quantity of work.

If, on the other hand, efficiency were measured by the proportion the heat absorbed by the water bore to the heat equivalent of the fuel used, then the Lancashire boiler was just as efficient as the locomotive boiler. Both could be made to transfer about 80 per cent. of the heat available to the water if the proper extent of heating surface were allowed. So far, perhaps, the locomotive boiler had the advantage, but size and rate of working were not everything. The locomotive boiler could not be worked with the feed water used in Lancashire boilers, simply because of its size and arrangement; because, in fact, it was a quick working machine. Thus, taking into account the circumstances under which it had to work, the author thought the Lancashire boiler was as efficient as any other boiler, and nearly as efficient as any boiler required to work under practical conditions could be made. He did not think there was room for any material improvement in the type of boiler, but he was sure there was room for improvement in proportioning boilers to their work, and in stoking them when so proportioned.

He had long thought that it would be a good thing for mill owners if stoking competitions could be held, as in France. A sum of money would have to be subscribed, a boiler fixed upon, a quantity of coal got in and well mixed, and a committee of judges appointed to weigh the coal and water, to analyse the coal and products of combustion, and to give a prize or certificate to the fireman who could evaporate the greatest weight of water from a lb. of coal. He had mentioned the matter to several persons, but nobody seemed to care about it. If the Association as a body, or some influential persons in the district would take the matter up, he was sure much benefit would accrue both to the mill owners and firemen.

Mr. Hardman would see at once, on referring to the paper, that the evaporation of 9lbs. of water per lb. of coal mentioned as one of the data for calculating the numerical example, was not an evaporation which would be obtained in practical working with feed water at 100°, for to obtain this rate of evaporation, 1,596 square feet of heating surface would be required, and this was more than any mill owner in this district would put down

to evaporate 5,000lbs. of water per hour. With feed water heated in an economiser or by steam, however, an evaporation of 9lbs. of water was frequently obtained under practical conditions. In the experiment described in the author's annual report for 1888, and referred to in the paper, an evaporation of 9·82lbs. of water was obtained under practical conditions, and in practical work, but the feed was heated to 206°, and the damper opening properly regulated. The author did not know the average evaporation in Lancashire boilers, but he feared it was considerably below 8lbs. per lb. of coal.

Mr. Constantine's question about forced draught he had already answered to the best of his ability.

Mr. Settle's question as to the best velocity of the gases was most difficult to answer shortly because its meaning was not clear. If it meant what was the best sectional area of the internal flues of a Lancashire boiler as compared with the volume of gas passing through them, the answer seemed to be that the sectional area was immaterial, provided it were sufficient to accommodate a boiler inspector, because the draft would always take the shortest cut to the chimney. If it meant what was the best weight of gas to pass over a given extent of heating surface per hour, the answer as regarded Lancashire boilers was given by the formulæ and data in the paper, and depended upon the quantity of heat each lb. of coal was required to transmit to the water. With regard to Mr. Siemen's views, the author thought that in general the best results would be obtained by allowing the gases to give off their heat by radiation until combustion was completed, after that the closer the contact with the plates the more quickly would the heat be absorbed. He said in general, because the statement was not universally true. Much depended upon the arrangement of the heating surface. Take the case of a locomotive fire box. Combustible gases, whether resulting from incomplete combustion or from dissociation, might impinge upon the back end sheet, *i.e.*, the sheet in which the fire hole was placed, and might be cooled down below the temperature at which they could be ignited and burnt, without detriment to the economical result, because they would have to pass through the body of flame in the fire box before reaching the tubes, and while passing would have their

EV.

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To illustrate Mr. M. LONGRIDGE'S Paper on "THE EVAPORATION OF LANCASHIRE BOILERS."

Fig. 2
Steam pressure - 40 lbs per sq in.
$t = 287°$

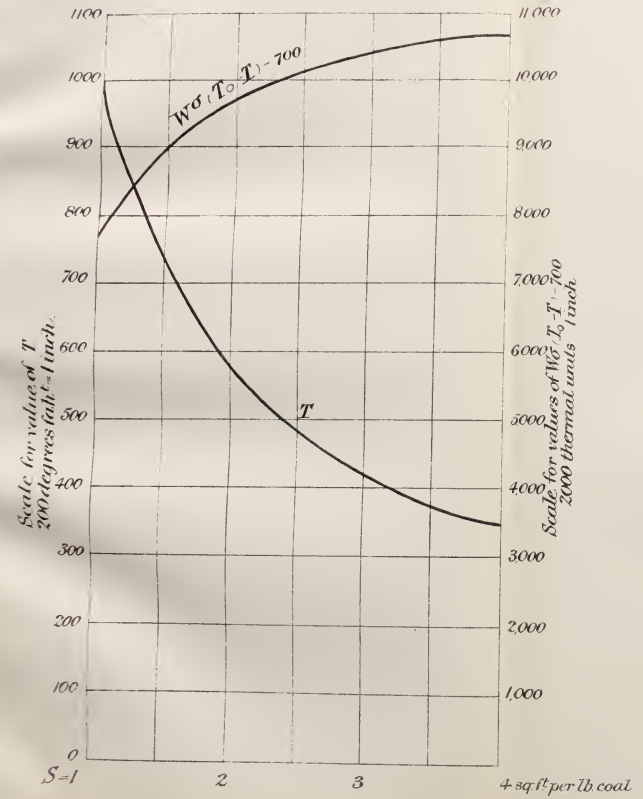


Fig 3
Steam pressure - 100 lbs per sq in.
$t = 338°$

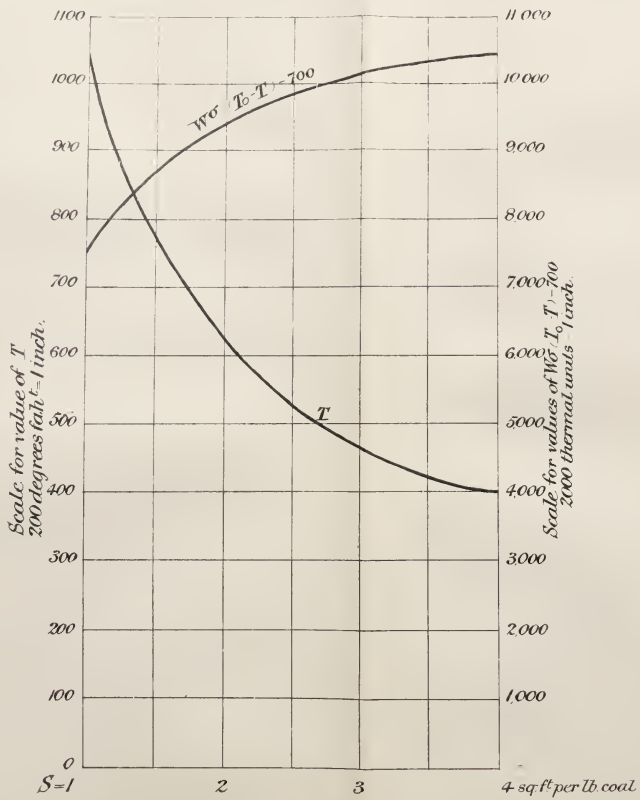
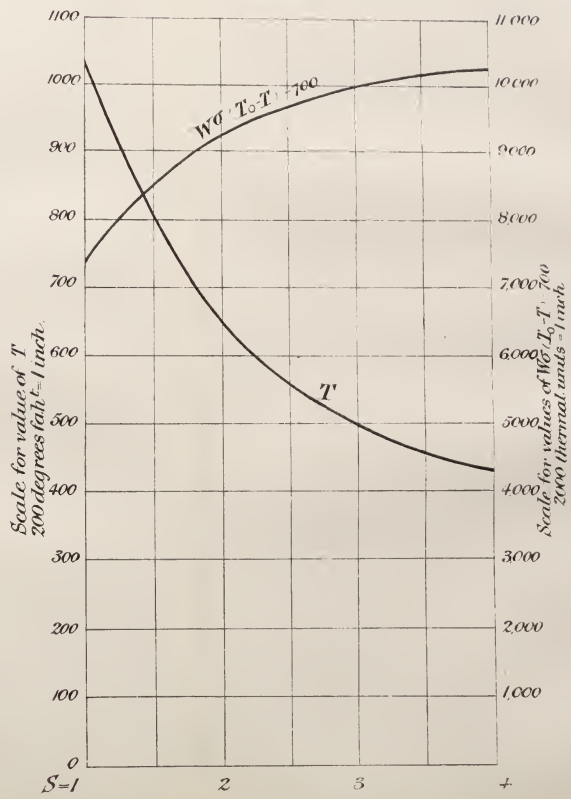


Fig 4.
Steam pressure - 160 lbs per sq in.
$t = 371$



CONTINUOUS BRAKES:

THEIR RECENT DEVELOPMENT.

A PAPER

READ BY

Mr. GEORGE KIERNAN,

On 22nd FEBRUARY, 1890,

AT THE GRAND HOTEL, MANCHESTER,

Mr. JOHN WEST, M.Inst.C.E., President,

IN THE CHAIR.

MANCHESTER:
HERALD & WALKER, PRINTERS, BACK POOL FOLD, CHAPEL WALKS.
1890.

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CONTINUOUS BRAKES: THEIR RECENT DEVELOPMENT.

Mr. President and Gentlemen,

Some three years ago I had the honour of reading a paper before this Association, on "Continuous Pneumatic Railway Brakes."

I did not at that time refer to what are known as *Quick-acting Brakes* for long trains, as nothing of a definite character had then been placed before the railway world; nor indeed, was anything in a sufficiently perfected state for the purpose.

I propose to-night to direct your attention, amongst other matters, to the quantity of passenger rolling stock which is fitted with various kinds of brakes; and afterwards to describe the two principal brakes as arranged for quick action on *trains of 50 coaches in length.*

Of the importance of the subject of railway brakes it is quite unnecessary for me to speak, for it is now almost universally recognised that a railway is incomplete without a continuous brake; and before very long, railway travelling will not be considered at all safe unless controlled by an *Automatic* continuous brake.

It is in a great measure, the continuous brake that enables trains to be safely run at the present high speeds of travelling; and if we had no such brake few people would care, for instance, to travel from Manchester to London in $4\frac{1}{4}$ hours, as is now so frequently done.

A few years since it was a vexed question as to whether continuous brakes should be of the *automatic* or the *non-automatic* form—the latter kind being commonly known as the "*simple*" brake, on account of its general simplicity.

The *Non-automatic* brake became extensively used throughout this country until the year 1887, when there was a very definite decrease in the use of this brake, and a more than corresponding increase in the use of the *Automatic* brake.

In 1877, ten years prior to the time I have just referred to, the Railway Companies were recommended by the Board of Trade to use a brake that complied with *five requirements*, which are now historical.

On the 30th August, 1889, about six months ago, an Act of Parliament was passed embodying these requirements.

The following is a quotation from Section 1 of this Act.

"1. The Board of Trade may from time to time order a "Railway Company to do, within a time limited by the order, "and subject to any exceptions or modifications allowed by the "order, any of the following things:—"

"(*a*) To adopt the block system. &c."

"(*b*.) To provide for the interlocking of points and "signals, &c."

"(*c*.) To provide for and use on all their trains carrying "passengers, Continuous brakes, complying with the "following requirements, namely:—"

"I. The brake to be instantaneous in action, and capable "of being applied by engine driver and guards."

"II. The brake must be self-applying in the event of any "failure in the continuity of its action."

"III. The brake must be capable of being applied to every "vehicle of the train, whether carrying passengers or not."

"IV. The brake must be in regular use in daily working."

"V. The materials of the brake must be of a durable "character, and easily maintained and kept in order."

Two month afterwards—24th October, 1889 –the Board of Trade forwarded a circular to all the Railway Companies calling attention to the Act, and stating that they "proposed that the "time limited for compliance with the orders should not exceed:

"For the adoption of Block Working—One year."
" Do. Interlocking—Eighteen months."
" Do. Continuous Brakes—Eighteen months."

It will thus be seen that the Board of Trade have recently fixed a time for the *complete adoption of Automatic brakes.*

A question might be asked, how is it that ten years elapsed after the Board of Trade made their recommendations before

the non-automatic brake began to be discarded by the Railway Companies ?

I venture to think the cause lay in the fact that, when the recommendations were made, a simple and reliable self-applying brake was more a theory than a practical reality ; and also that some years of experience were necessary to give the requisite confidence in automatic action.

The *principle* of self-acting Vacuum and Air-pressure brakes had been known for a considerable time, but their mechanism was not in a form which commended itself generally to railway engineers.

It is not however, the *principle* of an invention that ensures *practical success* ; it is as a rule the application to the *details*, of *skill, ingenuity, and persevering energy*, that makes success possible and achieves it.

The Automatic Continuous brake has been no exception to this rule, and only after years of study and hard work, has a brake been produced which complies with the Board of Trade requirements, and at the same time meets with the approval of the majority of railway engineers.

I do not propose to travel over the ground I covered three years ago, in describing the mechanism of the brakes in use, but a detailed reference to their *development* will probably be of general interest.

In 1878 an Act of Parliament was passed requiring Railway Companies to make half-yearly returns to the Board of Trade, on continuous brakes.

From the Returns last published—June, 1889—I find the following are the brakes in use, viz. :—

The Vacuum.
,, Westinghouse.
,, Chain.
,, Fay and Newall.
,, Steel Mc.Innes.
,, Heberlein.
,, Parker-Smith.

There are twenty-nine railways in this country, with a length of over 100 miles, and of these twenty-one or 72·5 per cent.

have *Vacuum* brakes, these brakes being in use in Great Britain on railways having a total length of about 12,000 miles, whilst the Westinghouse brake is used on a total length of 6,220 miles.

Of the chief Railway Companies which have adopted Vacuum brakes may be mentioned :—

The Midland.
,, London and North Western.
,, Great Northern.
,, London and South Western.
,, Lancashire and Yorkshire.
,, Highland.
,, South Eastern.
,, Manchester, Sheffield and Lincolnshire.
,, Great Southern and Western.
,, Great Northern of Ireland,

whilst of the principal Companies using the Westinghouse brake may be named :—

The North Eastern.
,, North British.
,, Great Eastern.
,, Caledonian.
,, London, Brighton, and South Coast.
,, Great North of Scotland.

Of all brakes none have become such a success in regard to *efficiency and reliability*, as those worked by the compression or exhaustion of the atmosphere.

The extent to which *Pneumatic and Mechanical* brakes have been and are being used, will be readily seen by reference to *Plate No.* 1; the horizontal spaces representing the half-years, and the vertical spaces the amount of stock fitted, each space of the latter indicating 2,000 vehicles.

The *Continuous Pneumatic* brakes are represented by the dotted line; and the *Continuous Mechanical* brakes by the full line. From this diagram we see that in 1878 there were in use some 4,350 *Mechanical* brakes. This number increased to a little over 9,000 in 1883, from which time there has been a decided falling off, till during the past year (1889) the number in use was under 3,000.

On the other hand the *Atmospheric* brakes in 1878 numbered about 3,380. In 1889 they had increased to 56,000.

Plate No. 2 illustrates the extent to which the different brakes, Vacuum, Pressure, and Mechanical, have been and are being used. The dotted line indicates the Vacuum, the Pressure being shown by the long and short dot, and the Mechanical by the full line.

In 1878 the following were in use, viz :—

Vacuum	2,415
Pressure	1,059
Mechanical	4,350

In 1881 the numbers were :—

Vacuum	8,700
Pressure	6,000
Mechanical...	8,600

And in 1889—

Vacuum	37,800
Pressure	18,000
Mechanical...	2,800

This shows that while in 1881 *Vacuum* brakes were in use to the extent of 45 per cent. more than *Pressure* brakes, and to an equal amount with *Mechanical* brakes; they (the Vacuum brakes) had increased in 1889 to 110 per cent. more than the *Westinghouse*, and 1,250 per cent more than the *Mechanical*.

Another question which arises as to the Pneumatic brakes in use is, how far have they been of the *Automatic*, and how far of the *Non-Automatic* forms ?

This is readily answered by *Plate No.* 3, which indicates that there has been no doubt whatever, for some years past, as to the popularity of the *Automatic* form. In 1878 the *Automatic* brakes were used on less than 1,000 vehicles, while the *Simple* in use were applied to nearly 2,500. In 1881 however, the *Automatic* had risen to 9,000, and the *Simple* to 5,700 only. In 1889 the figures were

Automatic	46,200
Simple	9,600

or nearly five *Automatic* to one *Simple*.

The next point I will consider is the rise and progress of the *Vacuum* and *Pressure (Westinghouse)* Automatic brakes, and the rise and fall of the *Non-Automatic (Simple Vacuum).*

This is indicated on *Plate No.* 4 from which it will be observed that in 1878 the Vacuum Automatic was used on 107 vehicles, the Westinghouse Automatic on 867, and the Simple Vacuum on 2,308. In 1881, the *Westinghouse* Automatic leads the way, being slightly in excess of the *Simple Vacuum*, and 72 per cent. more than the *Vacuum Automatic.* The Westinghouse retains the lead until 1887. The Vacuum Automatic overtakes the Simple Vacuum in 1883, falls behind it in 1885, but overtakes it again in 1887, and at this period, a junction is, as it were, formed by the three brakes meeting together.

The question of *Automatic* or *Non-Automatic* is henceforth decided. The *Vacuum Non-Automatic* brake is doomed, and loses ground rapidly, for in the two subsequent years we find its use reduced by twenty-five per cent. The *Westinghouse* in the same period is increased by six per cent., but the progress of the *Vacuum Automatic* has been so great that its use has risen seventy-two per cent.

This makes abundantly clear, the fact that as regards popularity, the Vacuum Automatic is now a long way ahead of any other brake.

Why is it that the Vacuum Automatic has advanced so rapidly in public favour, and has so completely left behind all its competitors ?

The reason is not far to seek. In the first place, the *efficiency* of this brake is second to none. At the same time its mechanism is so *very simple* that it is readily understood and easily kept in order. The brake is capable of the *greatest regulation*; it may be applied so lightly that the blocks scarcely touch the wheels ; or, it may *very rapidly*, be applied with its *full power.*

Again, it is devoid *of all machinery for producing its power*, an *ejector* worked by means of a steam jet, being sufficient for exhausting the air out of the apparatus ; consequently, no *complicated pump* is required.

As the brake is worked by the exhaustion of the atmosphere, the pressures are external, and so the bursting of any part of the apparatus is impossible. This is very advantageous when flexible pipes are absolutely necessary.

The following comparison will demonstrate the *simplicity* of the Vacuum Automatic over the Westinghouse :—

Both appliances utilize the atmosphere, as the medium for working and controlling the piston actuating the brake blocks. Both take steam from the boiler for the purpose of dealing with the atmosphere employed. A continuous pipe and a brake cylinder are common, and even up to a certain point, the working and the mechanism are the same, for a piston in each case is controlled by increasing or by decreasing the pressure in the train pipe.

There is however, this important difference : in the *Vacuum* the *piston* itself is made large enough to *apply the necessary power to the wheels*, whereas in the *Westinghouse* the piston is merely used *to control a valve* which admits air to and from the brake cylinder.

Thus, whilst the brake cylinders in the *Vacuum Automatic* are in themselves *self-acting*, in the *Westinghouse* they have to rely entirely for their action upon the successful manipulation of the air pressure *by other pistons*, and consequently the vital parts of the brake, *i.e.*, the brake cylinders are not in themselves self-acting.

Viewed in this light the Vacuum may be termed to be a *direct-acting Automatic Brake*, and the Westinghouse an *indirect-acting Automatic Brake*.

In my former paper I demonstrated that the Vacuum brake was more economical than the Westinghouse brake, as the *quantity of air* used by the Vacuum is very much less than that necessary for the Westinghouse. The air having to be compressed or exhausted, by the employment of *steam*, it necessarily follows that the Vacuum should be a more economical brake as far as the use of steam is concerned.

The *power* which a continuous brake is capable of exerting is readily understood by taking a train of moderate length, say 15 coaches. Such a train would weigh about 256 tons, and have an available brake force, approximately, of 156 tons.

When we remember that this brake power could be fully applied in two or three seconds, we get an idea of the brake's prompt and powerful action.

A great deal has recently been said in reference to the use of continuous brakes on long trains, consisting of 40 or 50 carriages. It is not within my province to discuss the question as to whether such trains will ever be employed in this country for passenger service.

I desire however, to show that continuous brakes *can* be successfully applied to such trains. With a train of 50 coaches, the length of the continuous pipe would, approximately, be 2,000 feet, or considerably more than one-third of a mile. If the brakes were not very quick in action, the *front* part of the train would be stopping before the *rear* had the brake applied, and the train would consequently be subject to severe shocks. These shocks would be entirely avoided if the application of the brake throughout the train could be *perfectly simultaneous*. This however, is impossible. Some little time *must elapse* before *all* the brake blocks are applied; but the shorter that time is the better.

A rapidly applying brake is of *paramount importance*, whatever may be the length of train, for the quicker the brake is brought into action, the quicker will the train be brought to rest.

So far as I am aware, no *mechanical* brake has yet been produced which is sufficiently rapid in action for use on long trains.

When it was desired to use *Pneumatic* brakes for the purpose, it was found that they were comparatively sluggish in action.

To remedy this defect, another agent was brought into requisition, viz.: *electricity*, not to *replace* the *Pneumatic* apparatus, but to secure its *rapid application* along the train.

This had the desired effect, although it was admittedly a very objectionable plan.

Then came the efforts to make the air brakes work satisfactorily on trains of any length, without the aid of what I may call a "foreign agent."

The *Westinghouse* brake was re-arranged, and was first tested in America. It has also been tried on the Continent, but has not yet been put to the test in this country.

The *Vacuum Automatic* brake was found to require but a *slight* alteration. This modification was made on 40 coaches and successfully tried last July on the Manchester, Sheffield and Lincolnshire Railway.

Another brake, known on the Continent as the *Wenger Compressed Air* brake has likewise been altered to meet long train requirements. As however, such brake is not used at all in this country, I do not propose going into any detail respecting it.

The trials which I have referred to, have proved that long trains can be satisfactorily worked by Pneumatic, Vacuum, or Pressure brakes.

As to the speed of application, *Plate No.* 5 is a copy of a diagram taken at the recent Brussels Exhibition, on a model of the Westinghouse quick-acting brake. The diagram was taken on the *last* of 25 cylinders, and shows the brake to have been fully applied in 2¼ *seconds*.

Plate No. 6 is a drawing to scale of a large model, representing the Vacuum Automatic Brake, which was erected at their works by Messrs. Gresham & Craven, of this City.

This model was constructed to illustrate the working of the quick-acting brake on a long train. The apparatus consisted of 50 cylinders, and had a length of 2in. piping equal to 1,830 feet. The piping commences at the combination ejector shown on the right of the drawing, and is arranged in a kind of double flattened coil, on the bottom of which are fixed the first 25 cylinders. Each two cylinders have the necessary length of pipe between them. The second 25 cylinders are placed at the top of the coils, and are attached to the return portion of the piping, so that the action of the 50th cylinder can be accurately gauged by a person standing at the ejector and working the model.

There is no connection whatever between the application valve on the ejector and the 50th cylinder, excepting through the whole of the 1,830 feet of piping.

Sir Douglas Galton, who is well known as an eminent specialist on Continuous brakes states that the Vacuum brake on the model referred to was applied—

On the 10th cylinder in $\frac{7}{10}$ seconds.
,, 20th ,, $1\frac{1}{2}$,,
,, 30th ,, $2\frac{1}{4}$,,
,, 40th ,, 3 ,,
,, 50th ,, $3\frac{1}{2}$,,

I may here remark that this record is scarcely the best that could be produced with the Vacuum brake, as the model on which the tests were made was fitted with only $1\frac{1}{2}$in. rapid-acting Valves instead of 2in. The latter size would have produced better results.

From these facts it will be seen that the *Westinghouse* brake was applied in $2\frac{1}{2}$ seconds on the 25*th coach*, and the Vacuum brake in $2\frac{1}{4}$ seconds only, on the 30*th coach.*

I will now proceed to describe these two Automatic brakes, the Vacuum and the Westinghouse, as re-arranged for this long train working.

As previously remarked, the Vacuum Automatic is but slightly altered from its ordinary construction.

The cylinder, the ball valve, the ejector, and the train pipe remain as before.

Each coach carries its own brake cylinder, with ball valve complete.

In what I have termed the *ordinary* arrangement, an extra admission of air takes place through a valve in the van when a full application of the brake is made by the driver, and this plan gives a very quick application for trains of the ordinary length. These additional valves for air admission are only brought into requisition when a *full and rapid application* of the brake is desired.

It is only the use of a *greater number of these valves* which is required to make the brake suitable for very long trains.

The branch from the train pipe to which the cylinder is connected, carries a *rapid acting valve*, which is simply a modification of the valve before mentioned.

The object and principle of this valve are precisely the same as that of which it is a modification, viz. : to admit air to the train pipe, and thus increase the rapidity of the application of the brake.

A quick application is effected by a sudden destruction of the Vacuum in the train pipe, between the driver's application valve and the first rapid acting valve ; this takes but a moment of time.

Each valve, when open, admits air, until the Vacuum is destroyed underneath the piston of the cylinder to which it is attached, and also in the length of train pipe between it and the next valve.

The valves opening in rapid succession along the train, cause a wonderfully quick destruction of Vacuum, and consequently a very rapid application of the brake.

Plate No. 7 represents this brake. The cylinder A is of the usual construction, and is generally of 18in. diameter.

With a Vacuum of 20 inches, this cylinder is capable of exerting a direct pressure of one ton. The piston is packed with a rubber ring B, circular in section, and similar to a bicycle tyre. When the piston moves up or down, the ring rolls in compression between it and the cylinder, and is a frictionless and air-tight packing.

The piston rod works through a *rubber packing* C, of new and peculiar construction. This packing has been recently patented by Mr. Gresham, and is of such a shape that only its centre part comes in contact with the rod. Such centre part is made of a lubricated compound which allows the rod to pass through it with a minimum of friction. The other part is very flexible, so that the Vacuum in the space above the bead allows the atmosphere to press the packing in, and make a perfectly tight joint.

The *ball valve* D remains exactly as before.

The *rapid acting valve*, another patent of Mr. Gresham's, is fixed on the train pipe, and consists of a *hollow stem valve* E, with *ball valve* H in centre, *diaphragm* N, the hollow stem of the valve having a pin I projecting into it.

As drawn, with the valve E upon its seating, there is a free passage for air from the train pipe to the cylinder, so long as the air is not admitted sufficiently fast to lift the *ball* H to its seating.

Air can consequently be admitted to, or withdrawn from the cylinder at pleasure, according to the amount of brake force required.

The pressure on the valve E is in excess of that under the diaphragm N, and therefore when closed, this valve is held tightly upon its seating.

Assume that a rapid application is desired. The driver opens his application valve, and suddenly destroys the vacuum in the train pipe, up to the first rapid-acting valve. This lifts the ball H to its seating, and reduces the vacuum below the valve E, so that the pressure on it becomes less than that under the diaphragm N, which then lifts the valve off its seating, and admits air to the train pipe through the holes K. The ball H being now carried upwards by the movement of the valve E, comes in contact with the pin I, which prevents it from moving further, and practically knocks the ball off its seating, thus allowing the air to flow to the underside of the piston and apply the brake. The air is prevented from flowing to the top of the piston by the ball L.

When the vacuum is fully destroyed above the diaphragm N, the valve again falls upon its seating.

A graduated application is obtained by the driver letting the air into the train pipe slowly, so as not to lift the ball H to its seating. The vacuum under the piston can then be partially destroyed in order to give the brake pressure required.

The brake is released in the ordinary way, by using the ejector on the engine, and re-creating the vacuum throughout the train.

The lever M is for the purpose of releasing the brake (by pulling a cord placed on each side of the coach) when it is desired to shunt a carriage which has been detached from a train.

The Westinghouse brake as before stated, has been considerably altered to fit it for long train service. *Plate No.* 8 illustrates this brake.

It has been found necessary to *increase the train pipe* from 1*in. to* 1½*in. diameter*, and the triple valve, already very complicated, has been made more complex still.

Like the Vacuum brake, the cylinder, reservoir and valve are now all combined in one fitting.

The *double piston cylinder* has been abandoned, and a single one A substituted. It is bolted to one end of the *reservoir* B, to the other end of which is attached, the so called triple valve.

By means of this arrangement the *Westinghouse* secures one of the advantages possessed by the vacuum, viz.: that of being very compact and contained in one fitting, requiring only a connection C from the train pipe.

The triple valve is altered in form, and has connected to it another valve, whose function is to reduce the time taken in applying the brake. That object is attained by admitting a portion of the compressed air from the train pipe to the cylinder, and so obtaining a more rapid means of reducing the train pipe pressure. This plan also utilizes some of the additional air necessary for filling the train pipe.

The so called triple valve has not only to control the admission of air to and from the cylinder, but also to perform the additional function of putting the rapid valve in action when required.

The triple valve now consists of *five different valves* (two of which together with a second piston, form the chief addition for rapid action) viz.: *a piston valve* D, *slide valve* E, *conical seated valve* F, *elastic faced valve* G, and *spring valve* H. There is also a *spring spindle* J, for the purpose of arresting the movement of the piston D in the regulating position.

Compressed air flows from the train pipe through the branch C, and passes to the space at the right of the piston D, forcing and holding the piston in the position as drawn. The air then passes through the small groove K, known as the "feeding groove," and thence past the slide valve E into the reservoir.

No air can as yet enter the brake cylinder, for its port is covered by the slide valve E. A groove L in the face of this slide valve keeps the cylinder in communication with the atmosphere through the port M in the valve body.

Now assume that an application is desired. The pressure in the train pipe must be released, when the air to the right of the piston D will be allowed to escape. The piston is forced to the right by the compressed air in the reservoir, it passes over the feeding groove K, and moves the slide valve E, closing the port N from the atmosphere, and opening it to the reservoir. The compressed air in the reservoir then flows into the brake cylinder and applies the brake.

A graduated application is made by this valve in exactly the same manner as with the ordinary arrangement of the brake. The pressure in the train pipe, and to the right of the piston D, is reduced slowly by the driver; the piston moves until it comes in contact with the spring spindle J. It opens the valve F and moves the slide valve E sufficiently, first to close the release port M, and secondly to open the valve F to the passage N. The air flows from the reservoir into the brake cylinder, until the pressure to the left of the piston D becomes less than that at the right. The piston is then again forced to the left, not with sufficient power to overcome the friction of, and move the slide valve E, but simply to close the conical valve F. By again very slowly diminishing the pressure in the train pipe the same action takes place, and the pressure in the brake cylinder is increased.

A *full and rapid application* is obtained in the following manner :—

The pressure in the train pipe having been suddenly reduced between the driver's valve and the first triple valve, the air pressure at the right hand side of the piston D is rapidly diminished, and this allows the pressure at the left to force the piston to the end of its cylinder, by overpowering the spring spindle J.

In the consequent movement of the slide valve E, the port O is opened to the reservoir, admitting compressed air on the top of the piston P, forcing it down and opening the valve G. The compressed air still in the train pipe, opens the valve H, and rushes into the brake cylinder by the pipe R (which runs through the reservoir) until the pressure in the cylinder is practically equal to that in the train pipe. Then the valve H is closed by its spring, and retains the air in the cylinder.

The reduction of pressure thus obtained in the train pipe, opens the valve on the next vehicle, and the same action takes place on that coach, and so on along the entire length of train.

When the triple valve is in the position just described, the port N is uncovered, and thus the cylinder is connected with the reservoir.

The compressed air in the latter continues to flow into the cylinder after the valve G closes, and until the *brake is fully* applied.

Having now described the quick acting brakes, I will ask your attention to the quantity of air they use.

Take a train of ten carriages with 400 feet of piping. The quantity of air required by the Westinghouse is 287,338 cubic inches, whereas by the Vacuum it is only 61,812 as shown by tables on page 74.

I would ask you to notice the fact, that the arranging of engines to work *long trains with the Westinghouse brake*, means greatly increased consumption of steam for ordinary trains. With the length of train just mentioned, the amount of air to be compressed is increased from 190,392 cubic inches—the amount required with the ordinary arrangement—to 287,338 cubic inches.

On the other hand there is *no increase whatever* in the use of air by the *Vacuum brake* under similar conditions. Indeed, the Vacuum only requires a little more than one-fifth of the air used by the Westinghouse.

Or take a train of 50 coaches and 2,000ft. of piping, and the advantage is still considerably in favour of the Vacuum, inasmuch as the Westinghouse requires some 2½ times the quantity of air necessary for the Vacuum. This is shown in detail by tables on page 75.

I have endeavoured to lay before you as truthfully as possible the rise and progress of Continuous brakes.

My remarks have been principally confined to the *pneumatic* form of brake, for the simple reason that none other has any practical existence in this country.

Quantities of Air required for 10 Coach Trains.

When fitted with

Vacuum Automatic Brake.

ARTICLE.	REMARKS.	Atmospheric air in cubic inches.
Vacuum Chamber for Engine and Tender.	(17½ins. dia. × 44ins. long,) 10,582 cubic ins. of air at 21 ins. of mercury. } =	7,408
Two cylinders for Engine and Tender.	(21ins. dia. × 12ins. long,) 8,312 cubic ins. of air at 21ins. of mercury. } =	5,818
Ten carriage cylinders.	(18ins. dia.) contents, 54,259 cubic ins. of air at 21ins. of mercury. } =	37,981
400 feet of piping and connections.	15,150 cubic ins. of air at 21ins. of mercury. } =	10,605
	TOTAL AMOUNT OF AIR ..	61,812

When fitted with

Westinghouse Automatic Brake.

ARTICLE.	REMARKS.	Atmospheric air in cubic inches.
Main reservoir.	15 cubic ft. = 25,920 cubic ins. of air at 95lbs. pressure } =	164,160
Two reservoirs for Engine and Tender.	(11½ins. dia. × 22ins. long) 4,570 cubic ins. of air at 75lbs. pressure. } =	22,850
Ten reservoirs for Carriages.	14,176 cubic ins. of air at 75lbs. pressure. } =	70,880
400 feet of 1¼in. piping and connections.	5,889 cubic ins. of air at 75lbs. pressure. } =	29,448
	TOTAL AMOUNT OF AIR ..	287,338

Quantities of Air required for 50 Coach Trains.

When fitted with

Vacuum Automatic Brake.

ARTICLE.	REMARKS.	Atmospheric air in cubic inches.
Vacuum Chamber for Engine and Tender.	(17½ins. dia. × 44ins. long) 10,582 cubic ins. of air at 21ins. mercury. } =	7,408
Two Cylinders for Engine and Tender.	(21ins. dia. × 12ins. long) 8,312 cubic ins. of air at 21ins. mercury. } =	5,818
Fifty Carriage cylinders.	(18ins. dia.) contents 271,295 cubic ins. of air at 21ins. mercury. } =	189,905
2,000 feet of 2in. piping and connections.	75,750 cubic ins. of air at 21ins. mercury. } =	53,025
	TOTAL AMOUNT OF AIR ..	256,156

When fitted with

Westinghouse Automatic Brake.

ARTICLE.	REMARKS.	Atmospheric air in cubic inches.
Main reservoir	15 cubic ft. = 25,920 cubic ins. of air at 95lbs. pressure. } =	164,160
Two reservoirs for Engine and Tender.	(11½ins. dia. × 22ins. long) 4,750 cubic ins. of air at 75lbs. pressure. } =	22,850
Fifty reservoirs for carriages.	70,880 cubic ins. of air at 75lbs. pressure. } =	354,400
2,000 feet of 1¼in. piping and connections.	29,448 cubic ins. of air at 75lbs. pressure. } =	147,240
	TOTAL AMOUNT OF AIR ..	688,650

The "Regulation of Railways Act, 1889," will have the effect of causing almost the whole of the passenger rolling stock of this country, to be very shortly fitted either with the Vacuum Automatic, or the Westinghouse Automatic brake.

The quick-acting brakes which I have described in detail, are not in actual use in this country. They show however what *can* be done with the Continuous brake, should it become necessary or desirable to equip long trains, such for instance as those employed for goods traffic.

Manchester may be justly proud of the part it has taken in the "Battle of the Brakes." It was a local line—the Lancashire and Yorkshire---on which Mr. Fay first fitted his Continuous hand-brake to a large amount of stock. It was on the Manchester, Sheffield and Lincolnshire Railway that some of the original trials of an Automatic Vacuum Brake took place. It is the same Manchester Railway on which, up to the present time, the only *long train trials* made in England have been carried out. The Lancashire and Yorkshire was one of the first railways to adopt the Vacuum Automatic brake, now so popular in this country, and used to a greater extent than any other brake. Moreover, it is in *Manchester* where the Vacuum brake is manufactured.

Now that the question of *automaticity* in a railway brake is definitely decided, would it not be wise to consider the advisability of adopting a *universal brake*, in order to secure thorough interchangeability of stock on all lines, and do away with the necessity of fitting up some vehicles with more than *one kind of brake*, as is the case at present.

I may add that the Vacuum Automatic brake has recently been adopted by the Indian Government, for use on the railways in that vast country.

I shall be glad, as far as I possibly can to give any further information that may be desired, or to answer any questions that may be asked, and will conclude by expressing a hope that we may have an interesting and instructive discussion on this most important subject of Continuous brakes.

DISCUSSION.

Mr. T. Daniels said it was very evident that Mr. Gresham had worked the Vacuum brake to a high state of perfection. Speaking personally as one who had to do with the fixing of brakes to locomotives, he might say that he had a preference for the small pipes, as they were easier to get in. He was of opinion that the difference between the weight of 2,000ft. of 1¼in. and 2in. piping would be very considerable, and the latter added more to the deadweight of the train. Mr. Kiernan seemed to attach great importance to the lesser quantity of air used with the Vacuum than with the Westinghouse Brake, but considering that air did not cost anything he (Mr. Daniels) did not think that was a very material point. The noise which the Vacuum Brake made at railway stations was certainly objectionable, and in that direction there was room for improvement. As far as he could learn there was a great reluctance on the part of engineers to use either of the two brakes upon steep inclines, the Heberlein brake being preferred in some cases. He concurred with Mr. Kiernan in the opinion that there should be one universal brake, which undoubtedly was desirable in every respect, and he thought the Vacuum was the most likely to win.

Mr. C. F. Budenberg suspected that members who had listened to the paper might be disposed to think that Mr. Kiernan, representing as he did the manufacturers of the Vacuum Automatic Brake, would be biased in favour of that system, but in the capacity of one who had taken the deepest interest in this subject from a perfectly neutral and disinterested point of view, he (the speaker) could honestly affirm that both as to facts and opinions, the statements advanced by Mr. Kiernan were substantially true and accurate. The new rapid acting valve which had been described, was an addition of the greatest value in its way, and the results as regards time of application obtained with the use of this valve were certainly very remarkable. He

had had an opportunity of seeing the action of the brake on the ten-coach model fitted in the yard of Messrs. Gresham & Craven's Works, and provided with these rapid acting valves, and as a result he could confirm the statement that the brake was applied to the tenth coach in about seven-tenths of a second, or at any rate in something less than one second, though he could not say definitely whether the length of piping on the model corresponded to that of ten actual coaches. The addition of this valve however, complicated the construction and action of the brake, and the Vacuum Automatic brake was no longer that extremely simple appliance, the understanding of which was within the scope of all who were likely to come into contact with it. The brake would also necessitate far more care in manipulation, for whilst previously a driver might move the brake handle to and fro at pleasure, applying the brake more or less as was desired, with the new arrangement if the handle were moved beyond a certain rate, the brake would go on full, and stop the train completely in a few seconds ; an occurrence which though not very serious in itself, might constitute a great nuisance if it were repeated frequently. Of course this was an objection which drivers would overcome with experience, more especially if the valve were made less sensitive than at present, but in any case with the vibration of the engine the control of the brake would be a matter of some difficulty, and the valve would be liable to operate when not required. The quick-acting valve however constitutes a very effective reply to the argument that the Vacuum Brake could not be made as rapid of application as the Westinghouse Brake, a proposition which had been frequently advanced to demonstrate the utter worthlessness of the Vacuum Brake as against the Westinghouse, as though the saving of a small fraction of a second in the time of application of two or three seconds were the only desideratum in judging the efficiency of a brake. Given the same power of application in two brakes; the argument that that must be the better in which the time of application is least, was convincing enough at first sight, and being easy of comprehension, it had been readily snatched up by many people who had based their judgment thereon ; but it must be remembered that the conditions imposed upon a brake by the exigencies of ordinary railway

work were of a far more complicated nature, and could only be fully appreciated by those who had gained extensive experience in the use of both brakes, and it was certainly a fact that wherever the two brakes had been tried alongside in this way the Vacuum Brake had always won the day.

Mr. Budenberg, continuing, said that a great practical advantage of the Vacuum Brake consisted in the perfect and easy control it afforded over the power both in application and release, whereas in the Westinghouse Brake the power given is always more or less a matter of guesswork, whilst in release the brake could practically not be regulated at all. The limit of power which could be advantageously applied in a brake is determined by the point at which "skidding" sets in, for as soon as that commenced the frictional resistance was greatly reduced, and since the pressure on the brake block at which skidding commences was greater the higher the speed, it follows that in applying the brake the most advantageous way of stopping quickly was to apply at first a great pressure, and then gradually reduce it during the stoppage, always keeping the pressure as little short of the skidding point as practicable. Now, since in the case of the Vacuum Brake the pressure could be gradually reduced in this manner, it would allow of a far greater initial pressure being applied than in the Westinghouse, where the power remained practically constant during the whole length of the stoppage. It was therefore evident that if the Vacuum Brake were manipulated in this way, it could be made very much more powerful than the Westinghouse. Mr. Kiernan had given the relative quantities of air used in these two brakes, and it had been hinted that the quantity of air used was of no consequence, but it must be remembered that the quantity of air operated upon, as well as the difference of pressures, would affect the *work done* in compressing or exhausting the air. If the curves of the work done in the two cases were plotted on the data given in the paper, it would be found that the work done in compressing the air in the Westinghouse brake would be from four to five times as great as in exhausting the corresponding quantity in the Vacuum Brake. Now, the efficiency of the air pump is much greater than that of the ejector, but nevertheless, the balance of economy is probably still in favour of the Vacuum Brake.

In conclusion, Mr. Budenberg said that the rise of the Vacuum Brake as shown on the diagrams given by Mr. Kiernan, was certainly very remarkable, and could leave no doubt that so far, at least, as this country is concerned, the Battle of the Brakes was at an end, and it would be safe to prophesy that in all other countries, notably the Colonies, where Air-pressure Brakes had not obtained a footing before the Vacuum Brake existed in its present state of efficiency, the Vacuum Automatic Brake would be the brake of the future.

Mr. E. G. Constantine remarked that he had had experience some years ago with the old Smith Vacuum Brake, and found it most effective and very useful and efficient on inclines. He thought no brake could be more simple in its construction.

Mr. J. Walthew asked whether skidding of the wheels could not be obviated, seeing that it prevented the train being brought to rest in the shortest distance ?

Mr. T. Ashbury, in moving a vote of thanks, interestingly alluded to a few early brake trials with which he had been connected, and commented upon the advantage which would accrue from the adoption of a universal brake, which he had no doubt would ultimately be the Vacuum. He admired the pluck of the Westinghouse people, but their brake he did not consider equal to the Vacuum Automatic.

Mr. Alderman Asquith seconded the motion.

The President, in putting the motion to the meeting, said it was very necessary that the best brake which could be produced should be adopted on their railways, and in reference to the efficiency of the Vacuum type, they were not merely relying on the statements of the reader of the paper, but also on the testimony of a many eminent engineers, who had expressed a favourable opinion upon its merits.

The motion was carried with acclamation.

Mr. Kiernan, in replying, said that in alluding to the desirability of a universal brake, his object was to state a useful point for discussion.

Referring to Mr. Daniels' remarks respecting the weight of the pipes, he was of opinion that it would not be difficult to make a pipe for the Vacuum Brake lighter than that which was necessary for the Westinghouse Brake, inasmuch as it had only to bear external pressure. On the other hand, the pipes in the Westinghouse had to resist an internal pressure, and consequently the bursting strain had to be provided for by the strength and weight of the pipe.

With reference to the question of the amount of air used, alluded to by Mr. Daniels, he pointed out that Mr. Budenberg had explained the advantage accruing from a brake using a small amount of air. At the same time he might repeat what he had already stated, that the less air required the less steam was necessary, and it was a well-known fact that it was cheaper to create a vacuum by the use of steam, than to produce an air pressure by the same means.

The noise alluded to was not caused by the Vacuum Automatic Brake under notice, but by the old Smith Brake which was now becoming obsolete. Even with this brake that objection was removed by having a "muffler" constructed so that the steam fully expands itself into a chamber before escaping into the atmosphere. In recent years another method had been adopted of doing away with the noise, by placing the ejector against the fire box inside the cab, instead of having it against the smoke box. This necessitates a long exhaust pipe being placed along the side of the boiler, from the ejector to the funnel of the engine, and that pipe in itself to a very great extent deadens the noise. He did not hesitate to say, from his experience in brakes, that the least noise was caused by the Vacuum Automatic Brake.

Mr. Daniels seemed to be under the impression that Pneumatic Brakes could not be used on inclines, but upon that point he could say that they had recently been tried upon long and steep inclines in India, and had proved satisfactory in every respect.

As regards the length of train pipe on the model referred to by Mr. Budenberg, it was about the same as used in a train of ten coaches.

Regarding the difficulty of regulating the brake, the application valve in use on the model had not been altered to deal with the quick-acting valves ; it was the same application valve which was used before the rapid acting valves were put on. It was a simple matter however to make the valve admit air slowly at first.

Referring to the question of skidding, Mr. Kiernan said the Vacuum Brake, when it had been applied and the speed of the train sufficiently reduced, the driver's handle should be put back to running position, and the small ejector would slowly recreate the vacuum, by which means skidding would be approximately prevented.

Experiments were tried some years since with a valve on the Westinghouse Brake, with a view of automatically preventing skidding, but the results were jerky stops and the valve was discarded, even by the Westinghouse authorities ; and no one, he thought, would deny that they had exhibited a great deal of ingenuity in working out anything which would tend to the efficiency of their brake.

Concluding, Mr. Kiernan said the great desideratum in a brake was simplicity, but at the same time efficiency should not be subordinate to it. As a matter of fact, no simpler brake was ever invented than the Smith Vacuum Brake, but it was not automatic. And hence, if a train fitted with it broke in two it was left without control ; whereas, with the Vacuum Automatic Brake the two portions in a similar case would be stopped automatically, and probably an accident prevented. He thanked them for the kind attention which had been accorded to his paper.

DIAGRAMS.

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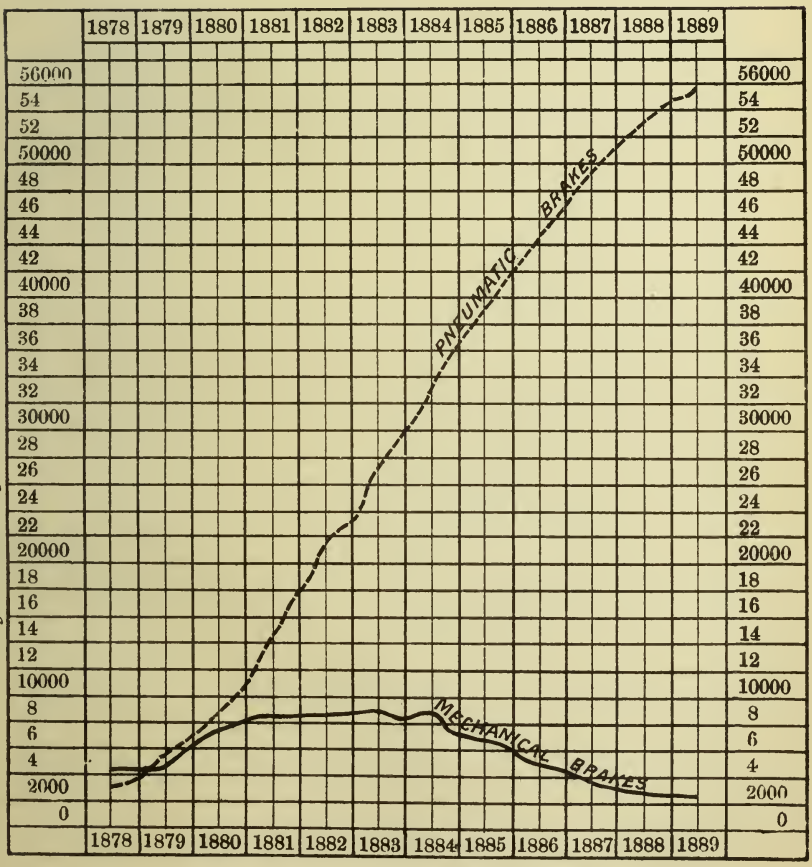
Plate 1.

PNEUMATIC AND MECHANICAL BRAKES.



THE LIBRARY
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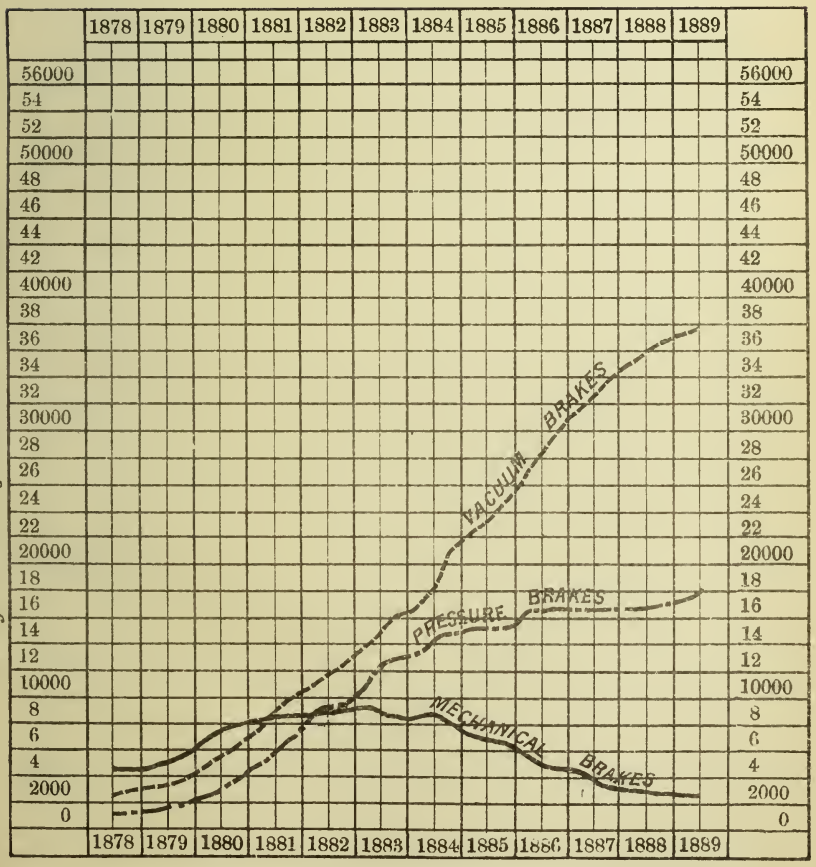
Plate 2.

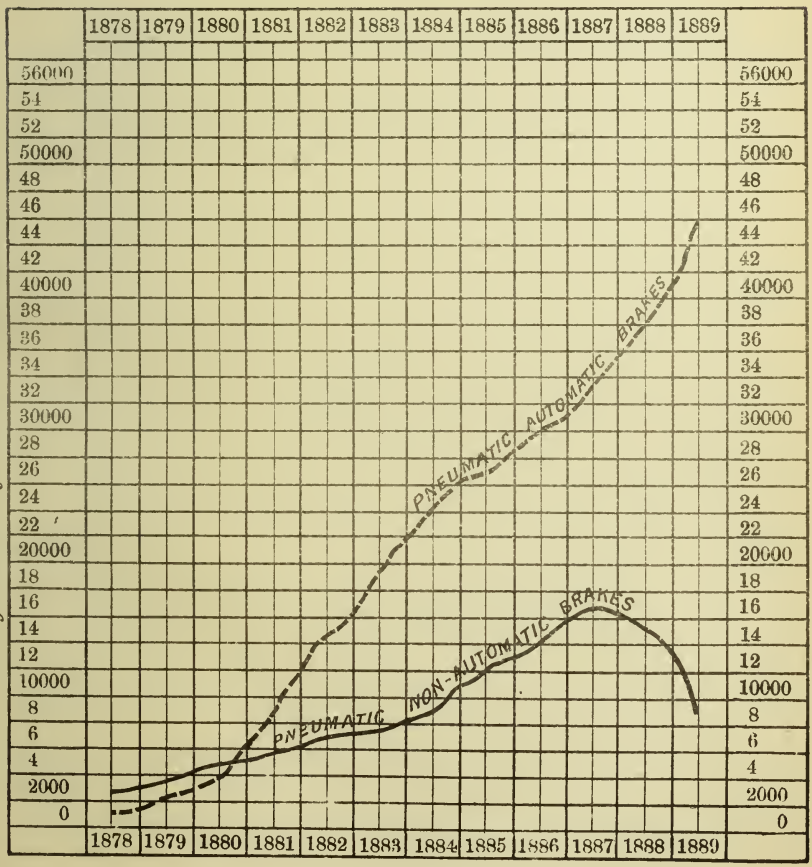
VACUUM,

PRESSURE, AND MECHANICAL BRAKES.

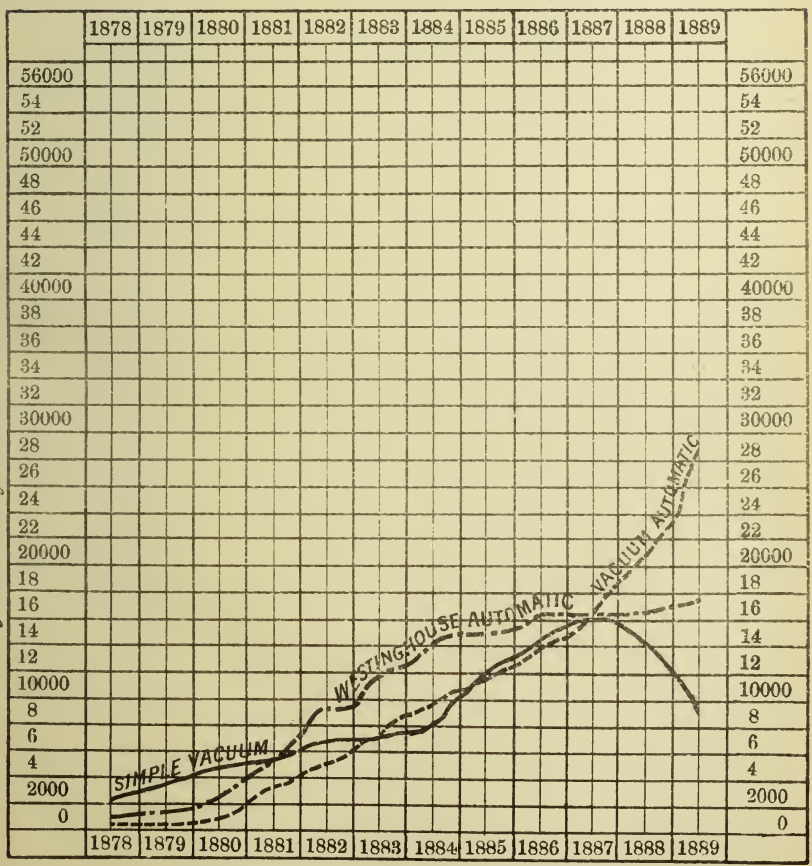


PNEUMATIC BRAKES,

AUTOMATIC AND NON-AUTOMATIC.



VACUUM AUTOMATIC AND SIMPLE, AND WESTINGHOUSE AUTOMATIC BRAKES.



WESTINGHOUSE QUICK ACTING BRAKE.

Diagram taken on 25th cylinder.

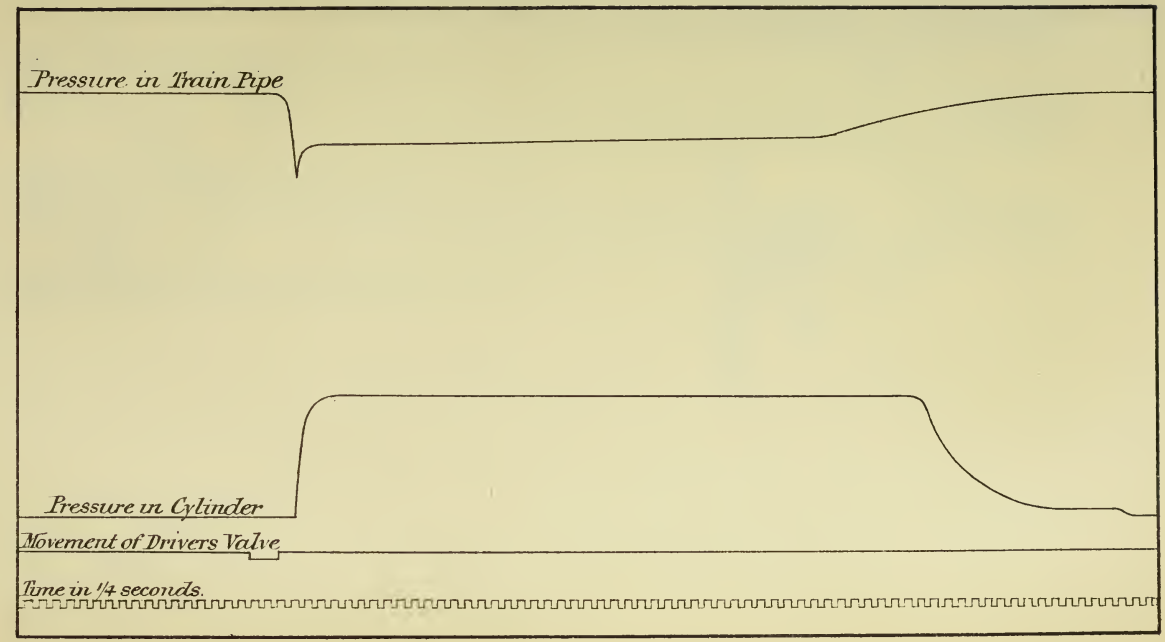


Plate 5.

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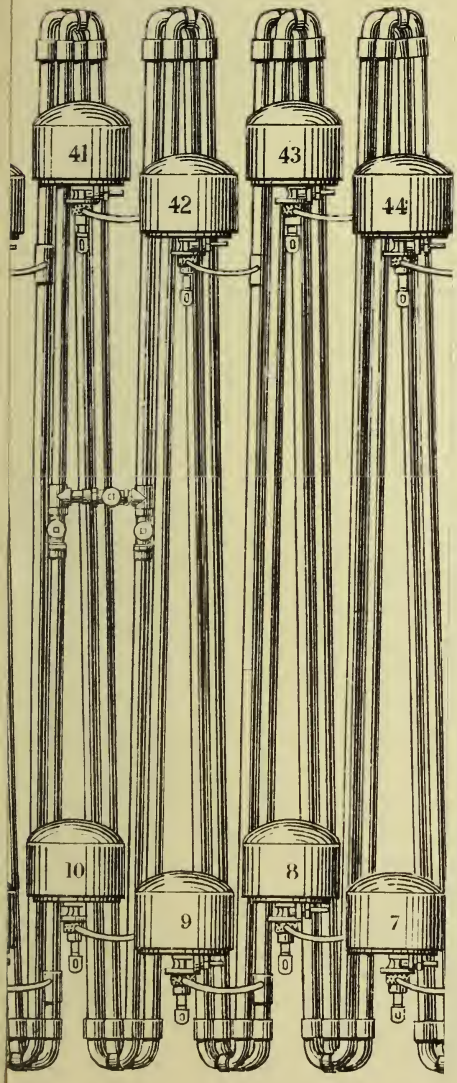
BRAKE,

H 1,830 FEET OF F

N'S WORKS.

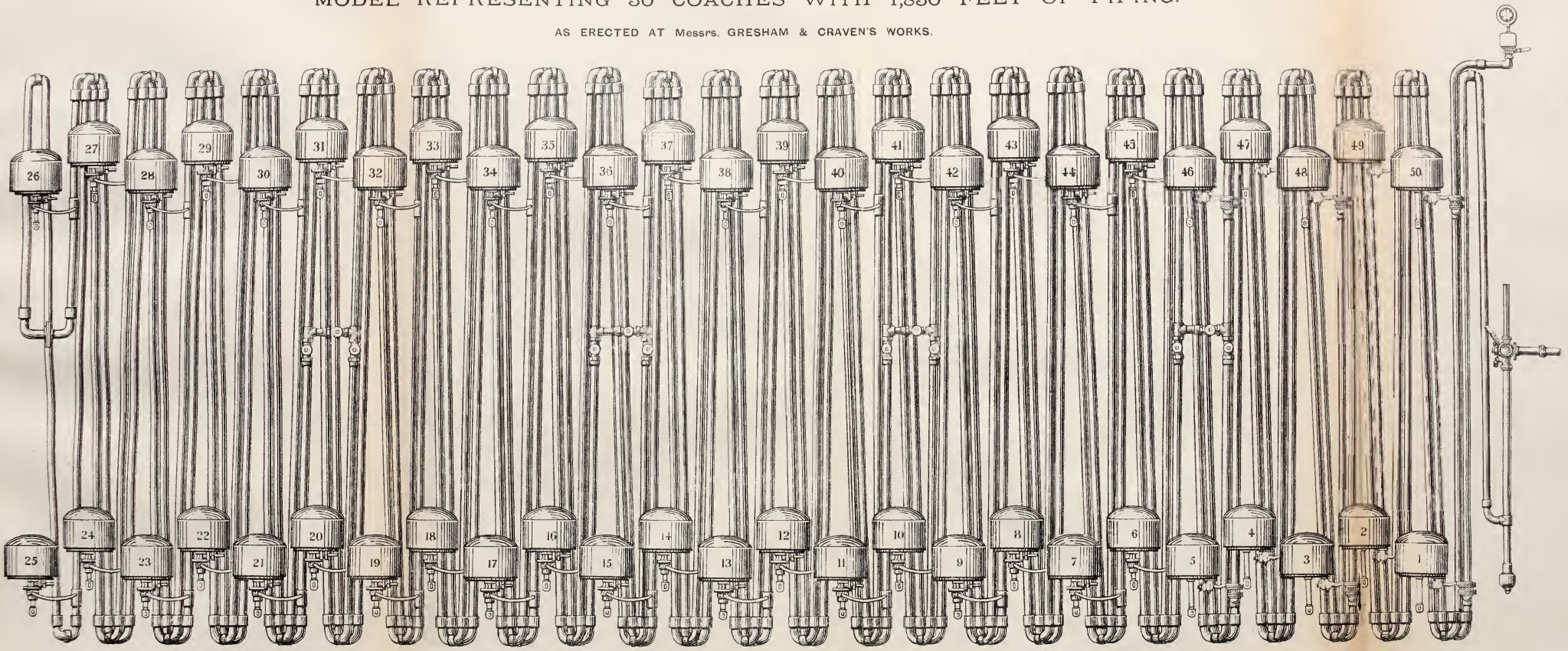


VACUUM AUTOMATIC BRAKE,

Plate 6.

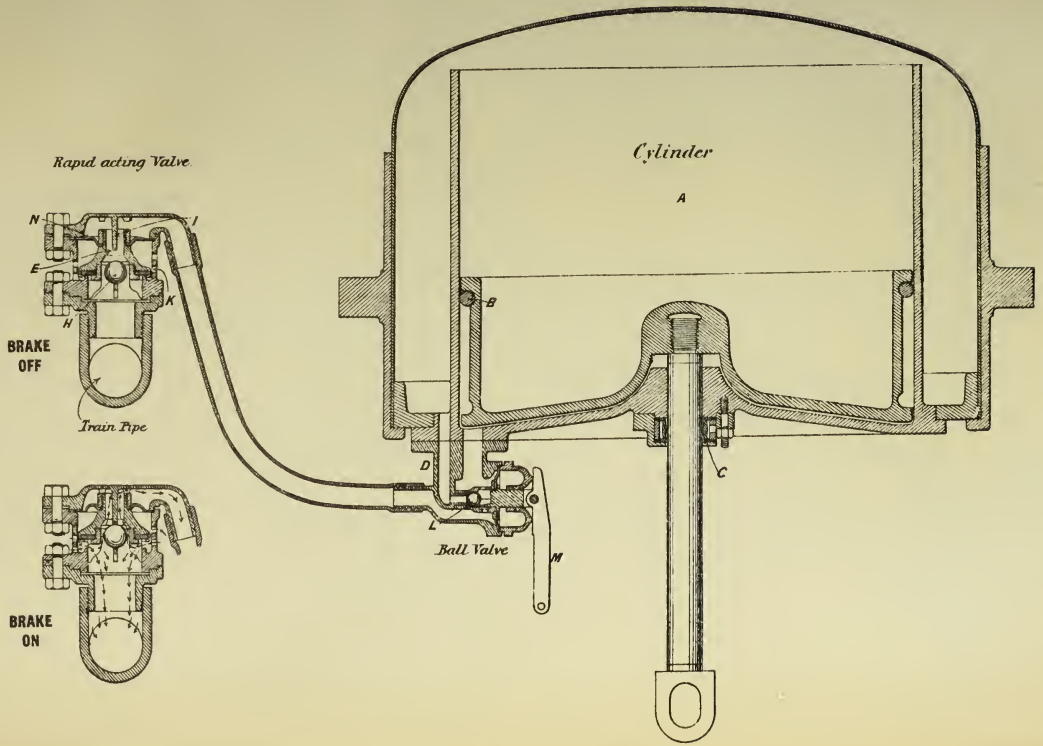
MODEL REPRESENTING 50 COACHES WITH 1,830 FEET OF PIPING.

AS ERECTED AT Messrs. GRESHAM & CRAVEN'S WORKS.



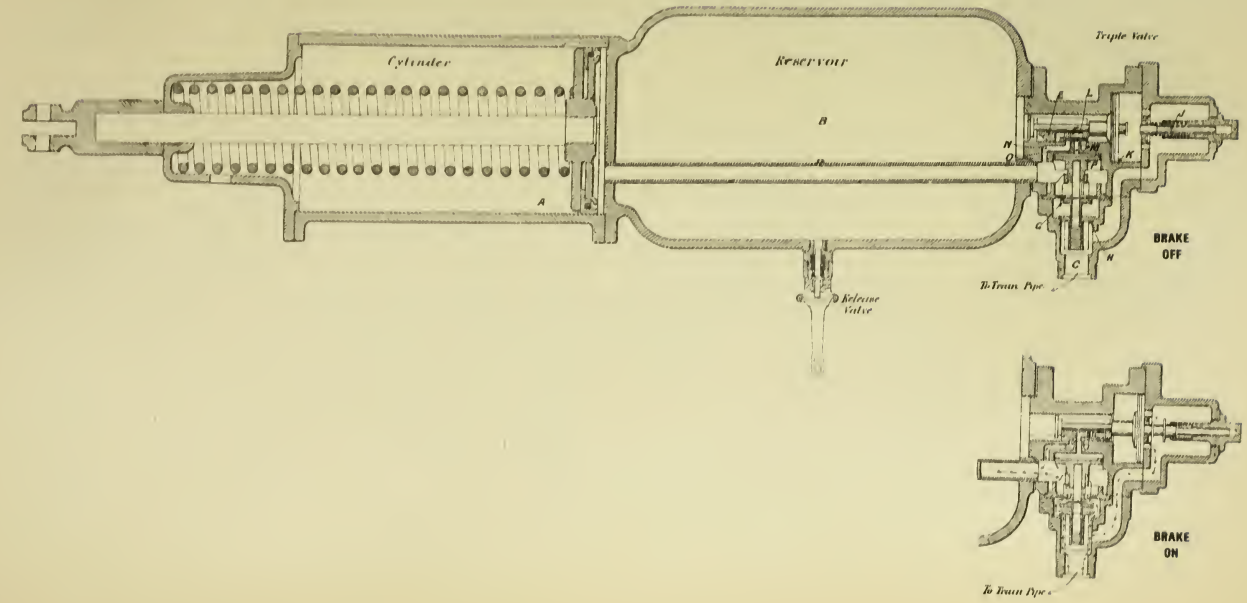
VACUUM AUTOMATIC BRAKE, FOR TRAINS OF 50 COACHES.

Plate 7.



WESTINGHOUSE AUTOMATIC BRAKE, FOR TRAINS OF 50 COACHES.

Plate 8



THE FRICTION AND LUBRICATION OF CYLINDRICAL JOURNALS.

A PAPER

READ BY

PROFESSOR JOHN GOODMAN,

Assoc. M.Inst.C.E., M.Inst.M.E.,

On 22nd MARCH, 1890.

AT THE GRAND HOTEL, MANCHESTER,

MR. JOHN WEST, M.Inst.C.E., President,

IN THE CHAIR.

MANCHESTER:

HERALD & WALKER, PRINTERS, BACK POOL FOLD, CHAPEL WALKS.

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THE FRICTION AND LUBRICATION OF CYLINDRICAL JOURNALS.

On every hand engineers are doing their utmost to effect the most rigid economy in steam engine practice, and for years have been devising various automatic cut-off gears, compound, triple and quadruple expansion engines, improved tubular boilers, &c., in order to reduce the consumption of steam and fuel. Their efforts have been rewarded with marked success, in fact to such an extent that some are even inclined to rest on their oars, believing that the greatest economy that ever will be effected has now been accomplished. The author will not express an opinion upon this point, but in the present communication will simply point out some methods by means of which the mechanical efficiency (*i.e.*, the proportion of useful work to the total work developed in the cylinder) may be considerably raised. In other words, how the friction of the working parts may be reduced, and thereby a considerable economy effected in the consumption of fuel, and of lubricating materials.

Out of every ton of fuel consumed for engine purposes, some 400 to 800lbs. are wasted in overcoming the friction of the working parts of the motor, and further, every machine driven by that motor also wastes a large percentage of the remaining power by its own friction. One would not be far short of the mark in saying that from 40 to 80 per cent. of the fuel is consumed in overcoming friction. This extremely wasteful state of affairs is most unsatisfactory, and happily can be greatly improved by a due observance of the laws of friction and lubrication. The author purposes in the first place to consider the laws which appear to regulate frictional resistance, and afterwards to point out the conclusions that may be drawn from them showing how they affect every day practice.

The subject of friction is capable of being treated from a purely scientific or mathematical point of view, for which thanks are due to Prof. Osborne Reynolds, who practically established

the true theory of lubricated surfaces, and by his mathematical investigations foretold many interesting and valuable points which have since been entirely corroborated by experiments. Such a treatment of the subject would however, be totally unsuitable on such an occasion as this. Few have the time or ability to acquire the higher mathematical knowledge requisite for the treatment of such a subject, and indeed it is an open question whether such knowledge would be of any value to practical men. The author feels sure that the subject, treated from a practical point of view, will be of far more value to the highly practical men whom he now has the honour to address.

The explanation of a few technical terms may not be out of place here :—

The load on the journal is the total pressure imposed upon it, which pressure may consist partly of a load due to dead weight, partly to tension of belts, or in the case of a connecting rod to the steam pressure acting on the piston, or in other cases to a variety of causes.

The load per square inch is the total load as defined above, divided by the nominal area of the brass, *i.e.*, the width of the brass (measured on the chord) multiplied by the length.

The frictional resistance per square inch is the total frictional resistance divided by the nominal area of the brass.

The co-efficient of friction is the frictional resistance divided by the total load or pressure on the brass, or simply the fraction of the total pressure that is required to make a body slide; thus if a ten-ton block of cast iron were resting on the table of a planing machine, and it required two tons horizontal pressure to make it slide, the co-efficient of friction would be 2 divided by $10 = \frac{1}{5}$ or 0·2, the two tons being termed the frictional resistance. If the area of the block in contact with the table were 200 square inches we should have a pressure of 112lbs. per square inch, and a frictional resistance of $\frac{2 \times 2240}{200} = 22{\cdot}4$lbs. per square inch.

In treating of the friction of lubricated surfaces, such as journals, &c., we shall see that the laws are of a totally

different character from those governing the behaviour of dry surfaces. The laws of friction for dry surfaces are usually—although they are not absolutely correct (see appendix)—taken as follows :—

The frictional resistance varies directly as the pressure between the surfaces, or in other words, the co-efficient of friction is constant, from which it follows that the frictional resistance is independent of the surfaces in contact.

The frictional resistance is independent of the velocity of sliding.

The laws of lubricated surfaces are by no means similar to these ; the friction of a lubricated surface is dependent on a great number of conditions.

But before dealing with each of these conditions it will be well to briefly glance at the most common forms of machines used for making frictional experiments.

Thurston's Machine (Manufactured by Messrs. W. H. Bailey & Co. Ltd., of Salford). Fig. 1 represents Prof. Thurston's machine. F the journal on which it is desired to measure the frictional resistance, is driven by a belt running on the pulley E. The brasses GG are fitted into the upper part of the pendulum HH ; the desired pressure on the brasses is applied by turning the hand screw K, which compresses the spiral spring S ; PP is a graduated arc traversed by the pointer O, which is attached to the pendulum. The quotient of this reading by the total pressure indicated by the pointer X gives the co-efficient of friction. On the top of the brass is a thermometer to register the heat of the journal ; R is a revolution indicator ; the lubricant is supplied through a small hole at T. When the journal revolves, the friction on the brass causes the pendulum to be deflected.

A somewhat similar machine to this is used by Prof. Smith, of Birmingham. Both machines are exceedingly convenient and undoubtedly the best for commercial purposes, yet they are hardly suitable for scientific work. No bearing in practice ever has the pressure on both brasses at the same time. The method tends to raise the co-efficient of friction unduly.

Tower's Machine. In Mr. Tower's machine, Fig. 2, a dead weight is substituted for the spiral spring, to give the desired

load on the brass. A is the revolving journal, B is the brass bearing carrying the frame C, on the lower part of which is a knife-edge C^1, situated immediately under the centre of the journal, from which the weight is suspended; D is a long light angle-iron frame with a scale-pan suspended from its extremity, into which are placed weights to counterbalance the turning moment of the friction; E is a pointer and graduated scale to indicate when the whole frame is in its normal position; H is an oil bath into which the bottom of the journal dips, and so keeps up a thoroughly good supply of lubricant.

In the construction of these machines the main point to be attended to is the proper balancing of the scale-pan arm, and to ensure that the knife-edge C^1, the centre of the shaft A, and the scale-pan knife-edge S, are the three angular points of a right-angled triangle; then when the two latter points are on a horizontal straight line, the two former are in a vertical line. The slightest error in the position of any of these points will lead to a large error in the results; the most convenient method of proving the accuracy of the machine is to mount it on a mandril, as described later on, and to mark the position of the pointer E before loading. When loaded it should retain its original position, but if there be any error of construction the pointer will occupy a new position, and the knife-edges and balance weight must be adjusted until the above condition is fulfilled. This machine is liable to be thrown out of balance by the uncentral wear of the brass.

Let r = radius of the journal = say $3\frac{1}{2}$ inches.

,, S = the error or the horizontal distance the brass has worn out of the vertical = say 0·01 inch.

Then the co-efficient of friction $u = \frac{S}{r} = \frac{0{\cdot}01}{3{\cdot}5} = 0{\cdot}0028$ which is the error due to the uncentral wear of the brass. There will also be a slight error due to the alteration of the length of the scale-pan arm, but this is negligible.

In designing one of these machines the knife-edge C^1 must be kept as near the centre of the shaft as possible, the further they are apart the less sensitive is the machine; the length of the arm D should be from six to eight times the distance of C from the centre A.

Stroudley's Machine. In this machine, Fig. 3, the essential difference from the last mentioned is the arrangement for applying the load to the brass. A is the revolving journal, several sizes of which are used corresponding to the various axles of a train; B is the brass bearing fitted into the weight beam C, at each end of which is a knife-edge carrying a weight suspending link D; G is a small scale beam and pan into which weights are placed to counterbalance the moment of friction; H is a small eccentric and wheel driven by a worm on the main shaft, which keeps the bearing continually moving to and fro to represent the side play always given to locomotive axles; M is an oil pad which keeps the journal constantly lubricated; N is a syphon lubricator; R is a revolution indicator; T is a thermometer to register the heat of the journal; P indicates when the beam is in its normal position.

This machine when accurately constructed runs rather more steadily than Tower's machine, consequently there is less liability to error in taking readings; the lubricating arrangements are easily accessible, the bottom of the shaft is quite open, which is not the case with the latter machine, where the weights are suspended from a central stirrup, thus leaving very little space for the baths, pads, &c. Then again the loads in the first machine are more accessible, from their being quite free from the framing, which is a very important point; the separate weights often are of very considerable size, sometimes $2\frac{1}{2}$ cwts. each. But on the other hand, there is a disadvantage in the Stroudley machine, in that the most scrupulous accuracy is required in making the separate weights exactly equal; the weight beam and links must also be exactly balanced. The balancing of the weights and beam is effected thus:—after the beam has been machined very accurately, so that the jaws in which the brass fit are central with the knife-edges on which the weights hang, a temporary knife-edge is fitted in the centre of the jaws, and the beam itself balanced upon it. The weight links are hung on and also balanced, then this knife-edge is removed, and the brass having been fitted in, is placed on a short mandril which it exactly fits. The whole is now placed on a smooth level plane, and the beam again balanced by adjusting the brass in the jaws until the centre of the mandril is central with the

knife-edges; by this means a practically frictionless vibrating motion is obtained. The weights themselves are placed on the links, and each pair balanced and marked.

After the machine has been running for some time its balance is disturbed, unless the brass is frequently reversed to keep the wear central. This matter of the inequality of the wear will be fully treated under the head of "wear of brasses." The inequality of the wear is occasionally very rapid under heavy loads, a few days hard running will cause the brass to wear 0·01 inch out of the centre. Suppose the load to be one ton or 2,240lbs., which with an equivalent weight arm of 72 inches, gives an error of $\frac{0{\cdot}01 \times 2{,}240}{72} = 0{\cdot}311$lbs. in the scale pan; this with a 7in. shaft becomes an error of 0·0028 in the co-efficient of friction (exactly the same as in the Tower machine), being in some cases more than 100 per cent. Thus a very small error in construction or unequal wear produces an enormous error in the results.

The beams of these machines must be made very strong for the sake of stiffness, if not, a great deal of vibration is set up when running. The brasses also should be very heavy and stiff, or else enclosed in a strong outer casing, otherwise they invariably open at the sides when the load comes on. The journal on which the experiments are made should be of larger diameter than the rest of the shaft to prevent deflection in it when fully loaded; overhung journals should never be employed under any consideration.

Goodman's Machine. This is a modification of the machine employed by Mr. Tower in his experiments on friction. In Figs. 4 and 5 A is the journal on which the frictional resistance of the brass B is to be measured, it is tightly fitted into the cast iron stirrup C, and the weights are suspended from it by the link D, which rests on the knife-edge E. The oil-bath F is filled with oil, into which the bottom of the journal dips; it is shown in detail in Fig. 6. A lubricator G is provided for syphon experiments; the temperature of the journal is kept constant by using the circulating water pipe H, the waste from which is carried away by the pipe J. The shaft is driven by the lathe chuck K, the revolutions of which are registered by the counter

L. The temperature of the brass is registered by the thermometer M. The arm O carries the scale-pan Q, which is suspended from the knife-edge S, the whole of which is counterbalanced by the weight N. The pointer P indicates when the arm is horizontal, the long arm of which is balanced by the small weight R.

The friction of lubricated surfaces is dependent upon the following conditions :—

(1) The intensity of pressure between the sliding surfaces.
(2) The velocity of sliding.
(3) The temperature of the journal.
(4) The shape of the brasses and position of oil grooves.
(5) The method of lubrication.
(6) The materials of which the sliding surfaces are composed.
(7) The time the load acts upon the bearing.
(8) The physical properties of the lubricant.

In friction experiments observations should be made of all these factors.

The intensity of pressure between the sliding surfaces. When we have perfect or very good lubrication, such as that obtained with a bath or saturated pad, the frictional resistance is practically constant under varying loads, as long as the temperature and speed remain constant, hence the co-efficient of friction under such conditions varies inversely as the pressure. Table 1 in the appendix gives the result of experiments which support this law. When it is remembered what a great number of conditions friction depends upon, it will be realized how exceedingly difficult it is to get uniform results, hence we are obliged to content ourselves with laws that are correct in a general sense rather than being absolutely accurate.

The results of the tests of the University College Steam Engine given in the same table are interesting, in showing how that the total friction on an engine is almost constant when working either light or heavy.

Hence with a well lubricated surface the friction varies in exactly the reverse way to what it does with a dry surface. A meagrely lubricated surface, however, is in an intermediate

condition, and consequently the way in which the friction varies with the pressure entirely depends upon the efficiency of the lubrication.

In support of this statement Table II. in the appendix is given, also some formulæ which approximately represent the results of experiments.

The velocity of sliding. Mr. Wellington, Prof. Kimball, and others, have found that the friction of journals revolving at very low speeds is abnormally high, and gradually decreases as the speed is raised to about 100 feet per minute, see Table III. (appendix.) Beyond that speed Mr. Tower's experiments show that the friction varies approximately as the square root of the speed when the lubrication is good (the load, in his experiments, was in every case over 400lbs. per square inch).

The author's experiments made in 1885 show that when the nominal load per square inch is below 60lbs. the frictional resistance regularly decreases with a reduction of speed; but when the intensity of the load is greater the frictional resistance increases when the speed falls below about 50 feet per minute; the exact point at which this change occurs cannot be well defined, as it is greatly affected by the load and temperature. The change points are clearly seen from the Figs. 6a, 7, 8, 9, 10 and Tables 6, 7, 8, 9, and 10. With low speeds a greater load than 60lbs. per square inch appears to squeeze the lubricant out, and consequently to increase the friction. If the speed remains constant, the load at which the change point occurs varies in an inverse ratio to the temperature. The lubricant becomes more fluid as the temperature rises, and is more easily squeezed out. Thus it is clear that a given lubricant, when used for low speeds, will only support a certain intensity of pressure at a certain temperature. Whenever the conditions of the author's speed experiments agreed with those under which Mr. Tower worked, his results also agreed very closely, for example, with loads above 60lbs. per square inch and bath lubrication, the frictional resistance varied as the square root of the velocity.

After the lubricant has been squeezed out the machine runs unsteadily and vibrates a great deal, which makes the readings difficult to observe and very uncertain. If the brass be gradually

loaded without jar the friction may be kept down very low, indeed far below its change-point, but on slightly jarring the machine the friction is instantly enormously increased, or if the brass be kept constantly moving laterally the load can be so adjusted when near the change-point that the addition of two or three lbs. on the brass will just pass the limiting load, and increase the friction tenfold.

The results, given in Table IV. in the appendix, may be of some interest, they show the pressure and temperature when the brass showed signs of seizing.

The temperature of the journal. Generally speaking the friction varies inversely as the temperature of the journal, so long as the temperature is not excessive, but it is quite impossible to formulate anything approaching a definite law, as the influence of the temperature varies so much with the nature and viscosity of the lubricant. The figures given in Table V. of the appendix clearly show this variation.

In making experiments to determine the influence which temperature has on friction, great care must be taken to arrange the bulb of the thermometer as near the surface of the journal as possible; better results will be obtained if the bulb be surrounded with mercury.

All testing apparatus should be fitted with water circulating channels to enable the temperature to be accurately regulated.

Shape of brasses and position of oil grooves. In 1886* the author made a very elaborate series of over a thousand experiments to ascertain how the frictional resistance would be affected by cutting away the sides of the brass; he constructed a special machine for the purpose, see Figs. 4 and 5 previously described.

The results of these experiments are fully shown in the diagrams, figs. and tables, Nos. 11 to 18, in the appendix, from which it will be seen that the frictional resistance of a brass may be enormously reduced by cutting away the sides; for example, if the width of the brass be made one half the diameter of the journal the friction will be less than one half of what it would have been with a semi-circular brass. The exact way in which

* A very full account of these experiments will be found in the proceedings of the Institution of Civil Engineers. Vol. lxxxix., page 421.

the width and friction varies is also shown in the appendix. It is needless to say that the results of these experiments fully confirm the practical experience of all railway men. On all the rolling stock in this country the width of the brasses are made about $\frac{5}{8}$ to $\frac{3}{4}$ the diameter of the journals. Although the friction diminishes as the width of the brass is diminished right down to line contact, yet the author does not recommend that brasses should be made less than about $\frac{7}{10}$ of the diameter of the journal; not only is the friction low at that width, but as will be seen later on the wear is least.

Position of oil grooves. Several years ago the author was engaged in making a series of experiments on the friction of railway axles. He observed that there was a continual stream of oil flowing up through the oil hole, and it struck him at once that if the oil could thus escape from the crown of the brass just where it was most needed, it must seriously impair the efficiency of the lubrication. To further investigate the matter he fitted the oil hole with a screw-down valve, and immediately found that when the valve was closed the friction was reduced almost exactly 25 per cent., and again returned to the higher value when the valve was re-opened.

It is perfectly clear that the off side of the brass, under such circumstances, must have been robbed of much of its oil, but when the valve was closed an oil cushion was formed on the crown of the brass. Subsequent experiments of the author on other machines entirely confirmed the results of the original experiment, and most clearly demonstrated that the practice of putting oil holes or grooves in brasses along the resultant line of pressure is radically wrong, and should be studiously avoided. Of course in the case of ordinary shafting in which the line of pressure passes through the bottom brass, an oil groove on the upper brass will serve its intended purpose.

In the same series of experiments the author attached a pressure gauge to a second oil hole communicating with the same oil groove, and found that with ordinary lubrication no oil pressure could be detected, but when an oil pad was dipped in oil and applied in a dripping condition to the journal the pressure immediately rose and gradually fell off as the supply of oil diminished. Of course no pressure under any circum-

stances could be obtained when the above mentioned valve was open. A very full investigation of this question of oil pressures was made by Mr. B. Towers for the Institution of Mechanical Engineers; he also found that it was impossible to lubricate a bearing by means of an oil groove cut along the crown.

Methods of lubricating. Many people imagine that as long as a bearing occasionally gets a few drops of oil from an oil can that it ought to run cool and with but little friction, but this is a most fallacious idea, both from a frictional and economical point of view; of all questions connected with bearings that of keeping up a continuous supply of lubrication is the most important. The three most common methods are (1) Bath or perfect lubrication, (2) Pad lubrication, (3) Syphon lubrication.

(1) *Bath or perfect lubrication.* In this case the bottom of the journal dips in oil and keeps it thoroughly swilled, and is of course the most efficient method of lubricating a journal. An objection is often raised that bath lubrication is only obtainable in special cases of scientific experiments, and that it is of little or no practical value. The great advantages arising from this system of lubrication are however undoubted, and the author has therefore designed a bath suitable for use with many forms of ordinary journals, and has found it to answer satisfactorily.

The arrangement is shown in Fig. 6, where A is the shaft carrying the brass B, to which the bath C is attached by the screws *h h*; the oil is prevented from leaking out at the ends by leather packing *d*. When running at high speeds the oil is carried round by the shaft and flies about in all directions; to prevent this a "baffler" strip, *e e*, is arranged slanting towards the centre, and approaches the shaft within about $\frac{1}{32}$ inch. Rings of oil form on the journal at each end of the bath, even at moderate velocities, which if not prevented will cause a great waste of oil. These are skimmed off by the lips at each corner *f f*. When properly fitted this bath will answer perfectly at 400 revolutions per minute. The author has not had an opportunity of trying it at a higher velocity, but believes it would be equally efficient at 1,000 revolutions. It can be made of cast iron, brass, or sheet metal. For friction experiments it must not be attached to the brass, as it would greatly increase the friction upon it. In Figs. 4 and 5 it is made with flat ends and wedged up tightly with wooden wedges *w w*.

Pad lubrication consists of a woollen or felt pad kept soaked with oil and lightly pressed against the journal by means of a spring; the necessary supply of oil is maintained by means of lamp cotton, which soaks it up from a reservoir below, or in some cases the pad is fed by an ordinary syphon lubricator. Pad lubrication may vary greatly according to the quantity of oil supplied to the pad; in some of the author's experiments the lower part of the pad stood in oil, and thus gave the maximum efficiency of pad lubrication; in other cases a very meagre supply of oil was used (0·02lbs. oil—0·05lb. pad), thus giving the minimum efficiency of pad lubrication. This system of lubrication is by far the best for all practical purposes, the reduction of friction is not quite so great as with a bath, but at the same time it is more economical in the consumption of oil, a bath being very liable to leakage. Another point in favour of the pad system is that the pad wipes off any grit that may get on the bearing instead of allowing it to churn round and round, cutting the surfaces. As an illustration of the extreme economy of the pad system the following experiment may be quoted:—A new pad weighing 14 drachms was supplied with 2¼ozs. of rape oil, and placed in contact with a 7in. journal, total load on the brass 4,984lbs. or 237lbs. per square inch; at the end of 319,660 revolutions, which is equivalent to 1,239 train miles, the oily pad was weighed and found to be 2oz. 2 drachms, hence only 1oz. of oil had been used; the revolutions per minute were 166, the mean temperature of the journal was 130° Fah., which rose to 145° at the end of the experiment, the mean co-efficient of friction was 0·010, which rose to 0·012 at the end of the experiment. This is certainly the best result the author has obtained, but in many similar experiments the equivalent distance was over 1,000 miles.

Diagram Fig. 17 shows the rate at which an oil wears out, the co-efficient of friction and temperature are recorded for each journey, the oil used was Price's Engine oil, the conditions of running were practically the same as in the above case.

Diagram Fig. 18 shows how the temperature rises with the number of miles run, in each case it gets to a normal value and then suddenly rises as the supply of oil diminishes.

Syphon Lubrication and all other intermittent systems of

dropping on to bearings are most barbarous, they not only waste an enormous quantity of oil but are very inefficient methods of reducing the friction. The intermittent action causes the friction to vary most widely, to such an extent that it is quite out of the question to attempt to get reasonably regular results with this system; the oil also runs away long before it is worn out.

Some time ago the author made some experiments to ascertain how rapidly oil deteriorates by use. A sample of oil was tested in the usual way, and some of the same oil was put on the journals along the shop shafting; a few days after, the oil that had collected in the drip pan was tested, the remainder in the pan being put back into a fresh bottle lubricator and used the second time on the same journal, and after passing through the journal a second time was tested again, and repeated several times. Each time the oil lost about five per cent. of its lubricating property, the temperature and friction both being higher. The author unfortunately cannot find the copy of the report on these experiments, so is unable to give actual figures, but is certain the loss was under rather than over five per cent. They distinctly showed that oil which has passed through a bearing is almost as good then as it was originally.

The relative values of the three systems of lubrication will be seen from the following figures :—

	Oil Bath.	Saturated Pad.	Ordinary Pad.	Syphon.
Towers	1·00	....	6·48	7·06
Goodman	1·00	1·32	2·21	4·20

Nature of the bearing surfaces. Some of the author's earliest experiments were made to ascertain the relative values of different metals for bearings; gun-metal of different mixtures and gun-metal with white metal patches was tried, also cast iron. There was practically no difference in the frictional results of the various gun-metals, but there was decidedly less friction when white metal patches were used. In one instance the outer bearings of the testing machine gave a great deal of trouble through heating. The brasses were taken out and half-inch holes

drilled all over the bearing surfaces and afterwards filled in with white metal. No further trouble was experienced even when working with much higher loads and velocities. Cast iron when well lubricated gave very good results, but is very liable to heat and cut if any water gets on the bearing. Some recent experiments of Prof. Smith, of Birmingham, show that Magnolia metal is a remarkably good metal for bearings, it will run either lubricated or dry, and under very high pressures without excessive friction or heating.

Time effect of loads on lubrication. If a spot of oil be placed between two plates of glass and the plates squeezed together the oil will gradually spread. The rapidity with which it spreads depends upon the viscosity of the oil and the pressure on the plates. If the plates are perfectly true and a heavy load be left on for a short time, almost all the oil will be squeezed out, but it takes a very appreciable time to do so. A comparatively small load acting for a long time will produce practically the same effect as a greater load acting for a shorter time. A somewhat similar action occurs in bearings ; when a journal runs under a constant load that load must be much smaller than if the load were only applied for a very short space of time.

In railway practice the dead load allowed on axles seldom exceeds 450lbs. to 500lbs. per square inch, while in connecting-rod ends, where the load is only applied for a fraction of a second, the load often amounts to 2,000lbs. per square inch on the big end, and 5,000lbs. per square inch on the gudgeon pins. Similar pressures are also found on the crank pins of shearing and punching machines, and apparently never give any trouble through heating.

Physical properties of the lubricant. The function of a lubricant is to separate the metallic surfaces of a journal, the resistance to sliding then becomes simply that of shearing the thin film of oil between the two surfaces. This film is exceedingly small and has been actually measured by the author. The apparatus he used is shown in Fig. 19, where A is a micrometer screw capable of measuring to 0·00001 inch, carried by a small bracket fastened to the brass, but electrically insulated from it by paraffined paper. B and C are terminals for attaching insulated wires to a weak voltaic cell and galvanometer. When

the micrometer touches the shaft the galvanometer is deflected; it being set so that there is contact when the shaft is at rest, but immediately it is put in motion the brass, with the micrometer, is raised and the circuit is broken. The screw is again set to just touch the shaft, the micrometer then indicates the height to which the brass has been raised. The original experiments gave erroneous results, but more recent experiments show that the film is about from 0·0001in. to 0.0004in. It may be well to note that this figure agrees with Prof. Reynold's calculation.

The shearing resistance of an oil is simply another term for its "viscosity," or sometimes termed its "body." Hence a film of lubricant having a high viscosity will require a proportionately greater force to shear than one with a low viscosity, or in other words the frictional resistance of a well lubricated bearing will depend upon the viscosity of the lubricant. From this point of view we ought to choose lubricants of a low viscosity, but there is another still more important point to be considered, viz:— A lubricant with a low viscosity is much more easily squeezed out from between the surfaces than one having a high viscosity. We must therefore choose our lubricant to suit the pressure it has to carry. At present there is very little published data on the question of what pressures a lubricant will carry under various conditions. It is hardly necessary to point out that the viscosity falls off somewhat rapidly with the temperature, which naturally accounts for the fact that the friction decreases with the temperature.

Diagram No. 7 and Table VII. show very clearly the effect of reducing the viscosity by increasing the temperature, as the temperature increased the lubricant was squeezed out at a correspondingly lower load per square inch. The viscosity of the lubricant used in these experiments was not taken at the time, but a sample of the same oil was tested about twelve months after, and gave the following results:—

Temperature, Fah...60°	70°	80°	100°	120°	140°
Viscosity.....230	150	112	60	28	18
(Rape).....100					

It is very often found when oil is used as a lubricant for bearings, much difficulty is experienced from heating and seizing, yet when a solid lubricant is used it runs perfectly, although the natural co-efficient of friction and temperature of the latter are much higher than of the former.

The natural co-efficient and temperature are those to which a bearing attains when running with an ample supply of lubricant, under a given load and speed. Thus, from a commercial point of view, these natural values do not give the true value of the lubricant, and a further test is necessary, namely, to find the co-efficient of friction of rest after the bearings have been standing some hours. The reason of the excessive heat generated when oil is employed is probably due to the oil being squeezed out when standing, then with the first revolution of the shaft abrasion takes place on account of the surface being dry, which necessarily causes a great deal of subsequent heating and frictional resistance. On the other hand a solid lubricant is not squeezed out by standing, so that there is always a film of it left between the surfaces. Table XIX. gives the results of the author's experiments which support this view, the nominal load per square inch on the brass was 581bs.

The experience of railway engineers also corroborates this view; it is found that an engine often has considerable difficulty in starting a heavy train out of a station when oil axle boxes are used, whereas with grease boxes the engine will start off easily, but after once getting started the train with the oil axle boxes runs much more freely than with the grease boxes.

Wear of Brasses. When the width of a brass is reduced, in order to diminish the frictional resistance, the arrangement should be such that the resultant line of pressures on the bearing bisects the chord at right angles, in order that the wear shall be symmetrical about that line. Yet even when this precaution is taken, the brass does not always wear centrally, but acts in a peculiar manner. A brass is shown (Fig. 20) bored too large for the shaft, so that there is only line contact between them, when the shaft revolves the brass is carried forward in the direction of the arrow, consequently the brass is worn more on the on-side than on the off-side. But the author has found that with a *well-fitting* semi-circular brass the wear is

exactly the reverse, that is, the wear now takes place on the off-side, and continues to do so until it subtends an angle of about 100°, when the wear becomes central. If the chord be still further reduced, the brass behaves like the one which fits its shaft loosely, the wear taking place on the on-side. The author also found that the wear was practically central between 80° and 100°.

The brass which was used in the first part of the experiments was plain, without any oil groove. In a second set of experiments a brass with an oil groove and an oil-hole was used, the wear then invariably took place on the off-side, even with the narrowed chords in contact, and with every system of lubrication, the wear was also much more rapid than before.

The cause of these peculiar effects is not altogether clear. The author thinks that the surface of the brass in contact is not equally lubricated, and this opinion is supported by other investigations of the author, hence where the lubrication is deficient the wear is greatest.

Evidently two different forces act on the brass; one force is its tendency to be carried forward by the revolving shaft, the other is the wedging action due to the clinging of the oil-film to the shaft, so that when the lubricant on the shaft meets the on-edge of the brass, it must either be skimmed off by it or it must get in between the surfaces, and so force the on-edge away from the shaft. The direction in which the brass moves is dependent upon the horizontal component of these forces, and the wear will take place on the side opposite that in which the brass moves. Whether the oil ever gets in between the shaft and brass will depend upon the normal pressure at the on-edge. With a semi-circular brass and vertical load this pressure is zero, and the oil gets in without difficulty, but as the brass is reduced in width this pressure increases to a maximum with line contact. Let the first named of these forces be called $\propto$, and the second β. Fig. 21 represents a semi-circular brass, from which it will be seen that the on-side is thoroughly lubricated, and the off-side is nearly dry; this is a case in which the force β is greater than $\propto$, so that on putting the shaft into motion the brass moves diagonally in the direction C B, and wear takes place on the off-side. When the arc in contact is much reduced, the action of β is reduced on account of the

increased normal pressure, until a point is reached when $\alpha = \beta$ and the brass remains central ; the film of oil is then equally distributed over the whole surface in contact, and the wear is consequently central. (Fig. 22.) If the arc in contact be still further lessened, β is so much reduced that α becomes greater than β, the brass moves in the direction of α, and the wear takes place on the on-side of the brass. Generally the force α will vary with the frictional resistance of the brass.

Fig. 23 represents a brass where an oil groove is cut along its crown, and an oil-hole is drilled through the top of the brass into it; the wear in this case in invariably on the off-side, which is probably due to the oil escaping as soon as it reaches the crown of the brass, and so leaving the off-side almost dry, where the wear consequently ensues. This method of cutting oil grooves cannot be too strongly condemned ; for not only is the friction enormously increased, but a bearing cannot be lubricated in this fashion if a syphon only is used. The author has repeatedly proved the truth of this assertion experimentally ; if however a small scratch be made from the oil-groove to the end of the brass the oil will flow, but the lubrication will be imperfect. Although many railway axle-bearings made in this way give fairly good results, it must be remembered that there is a great deal of jar on them, which allows the oil to get between the surfaces better than it would if the motion were steady; and again, pads are used as well as syphons in every case in railway practice. As previously mentioned this uncentral wearing of brasses causes an infinite amount of trouble in friction testing apparatus, for it entirely upsets the balance of the machine unless carefully watched and guarded against. The author recommends that the bearings should be made to subtend an angle of 90°, then the wear is very nearly central; no oil grooves must be used. He finds that the best practical way of keeping the machine in balance is to keep a standard sample of oil, and when the machine is in perfect balance to find its co-efficient of friction under certain circumstances, which can be easily repeated. Then at stated intervals try the machine with the standard oil, and adjust until it is brought back to its proper balance. It is not an over scientific method, but still the author believes it to be the best for practical purposes.

Practical hints on the design and management of bearings. Having examined many of the most important factors that determine the friction of journals, we will now see how they affect the correct designing of bearings. The first point to be considered is, what load per square inch may be allowed on iron or steel journals running in gun-metal bearings. No hard and fast rule can be laid down, for the load per square inch must depend upon a great many circumstances. With very high speeds a much smaller load is admissible than with moderate speeds, and when a journal is likely to be neglected and irregularly oiled, or not automatically fed, the load per square inch must be considerably less than would be allowed for bath or pad lubrication. As above mentioned, when the pressure is intermittent a much higher load may be allowed than when the pressure is steady.

Instead of taking the load per square inch as a basis in designing bearings, the author takes the number of thermal units a given area is capable of conducting away per minute. The result of several thousand experiments show that a gun metal bearing working on a steel axle will keep cool when one square inch of surface is allowed for every thermal unit conducted away per minute.

Let P = total pressure in pounds on the journal.
u = the assumed co-efficient of friction.
S = the speed of journal surface in feet per minute.
A = nominal area of brass in square inches, *i.e.*, length × width of chord.
r = revolutions per minute.

Values of u.

	Above 100ft. per min.	Below 100ft. per min.
Bath Lubrication	0·010	$\frac{0·10}{S}$
Pad ,, ...	0·012	$\frac{0·12}{S}$
Syphon ,, ...	0·015 to 0·020	$\frac{0·15}{S}$ to $\frac{0·20}{S}$

Then the frictional resistance $= P\,u.$
Foot lbs. of work done per minute $= P\,u\,S.$
Thermal units generated per minute $= \frac{P\,u\,S.}{772}$

Then $A = \frac{P\,u\,S.}{772}$

In the case of journals running at excessive speeds, such as 2,000 or 3,000 revolutions per minute, a much larger bearing area must be allowed. The general formula for all speeds then becomes

$$A = \frac{P\,u\,S}{772}\left(1 + \frac{r}{600}\right)$$

This empirical formula gives much better results than any the author has yet come across, and possesses the advantage that it is very easily remembered and worked out.

Whenever practicable journals should be allowed a certain amount of end play, about one per cent. of their length, they will then run much more smoothly, and the axle will not wear in grooves. Those accustomed to use oil testing machines will at once recognise the great importance of attending to this apparently unimportant detail.

The brasses should never subtend more than an angle of 90°, the sides being cut away and pads inserted. The author's design of a bearing is shown in Fig. 24. An engine fitted with such bearings was recently tested in London, the mechanical efficiency was over 90 per cent. The report further stated that "The small amount of lubricant used during the experiment was very noticeable indeed." In fact the friction with such a bearing is less than one half that of an ordinary bearing, and only requires about one quarter the quantity of lubricant, also the cost of manufacture is much less on account of only half the quantity of gun metal being required.

The lubricant best suited for a journal should be found by experiment, and having been once found it should always be used. Nothing tends to make a journal heat more than constantly changing the lubricating material. In spite of great care one occasionally has to deal with hot bearings. The usual antidote is either plumbago or sulphur and oil; they should be of the finest impalpable powder. If gritty they will do far more harm than good.

Ball Bearings. Although ball bearings are but little used for engineering purposes, yet they are a most interesting study, from the extremely low frictional resistance, even when working almost dry. The author believes that it is only a matter of time before they will be very extensively used for heavy bearings.

Prof. Hele Shaw in his Cantor lectures on Friction quoted several instances where they have been used for heavy work with very marked success. The results of the author's experiments may possibly be of some interest.

The experiments were carried out on an ordinary "Rudge" bicycle bearing.

The apparatus for measuring the friction is shown in Figs. 25 and 26; the bearing contained eleven $\frac{5}{16}$ inch balls, and was mounted on a frame. The spindle A $\frac{3}{4}$ inch in diameter, was fitted with a hardened steel sleeve B, in which a groove was turned to keep the balls in position. C is the case of the bearing, which is clamped in the frame D by bolts, the lower one of which, F, formed the knife-edge for suspending the weight link. The spindle was supported at its outer end by the lathe headstock H. The revolutions were indicated by the counter. The arm K with its scale-pan L was balanced by the weight M. The pointer N indicated when the arm was horizontal. O is a dash-pot for preventing vibration of the arm. The diameter of the sleeve B is one inch. The diameter at the bottom of the groove is 0·875 inch. The mean diameter at which the balls bear is 0·978 inch. They do not touch the bottom of the groove. The radius at which the frictional resistance acts is 0·489 inch. The length of the arm K is 14·69 inch, therefore the leverage of the machine is $\frac{14{\cdot}69}{0{\cdot}489} = 30$ to 1. Then if $x =$ the weight in the scale-pan in lbs., the total frictional resistance is $30\,x$, and the co-efficient of friction is $u = \frac{30\,x}{W}$ where W is the total load on the bearings in lbs.

The method of experimenting was the same as that described for plain bearings, the lubrication however was not continuous; the bearings was thoroughly oiled before each experiment. Great difficulty was experienced at first with excessive vibration, but was effectually overcome by fastening with a fine wire, to the

bottom of the scale-pan, a thin leaden disk, which was placed in a bucket of water.

It is a matter of great importance to have the bearings adjusted neither too tightly nor too slack. In the latter condition the case C bears on the central sleeve B at R R (Fig. 27), instead of being supported by the balls; this occurs more frequently with heavy than with light loads, and hence the bearing must be adjusted to suit the load it has to carry.

The results of the experiments are given in Tables XX. and XXI., also in Fig. 28; as they are somewhat limited, no definite laws can be deduced for every form of ball bearings, but the following laws appear to hold for the special bearing used :—

(1) The co-efficient of friction of ball bearings is constant for varying loads, hence the frictional resistance varies directly as the load. (2) The friction is unaffected by a change of temperature.

The experiments with the white neutral oil are rather irregular, but a mean of them shows clearly, as with the pale American oil, that the co-efficient of friction is nearly constant, and when this is the case the frictional resistance varies directly as the load.

The second law was found thus :—The bearing was heated by a Bunsen gas-burner, from 20° to 60° C, but no difference could be detected in the friction; it was then allowed to cool whilst running, but without any appreciable change. This experiment was repeated with different lubricants, loads and velocities, with the same result.

The co-efficient of friction with ball bearings is rather higher than that of plain bearings when bath lubrication is used, but it is lower than when they are lubricated by the ordinary methods. They will also run easily with a much smaller supply of oil than with a plain bearing, hence there is a decided advantage in favour of ball bearings.

An experiment was made to find what load the bearing would carry, the revolutions were 100 per minute, and loads were added by 10lbs. at a time; on reaching 587lbs. one of the balls broke, and from the appearance of the fracture it was evident that there was a flaw in the metal. Another ball was substituted and a second experiment was made. When the load reached

610lbs. the belt slipped so much that the back gear of the lathe had to be put in, which reduced the revolutions to 20 per minute. When the load reached 1,250lbs. the bearing began to to grate and whistle, even with a fresh supply of oil; on removing the load the bearing was taken to pieces and examined, and to all appearance was as good as ever. The friction was very great with the high loads, and the machine vibrated to such an extent that it was impossible to measure it.

Tabulated results of all the experiments mentioned in this paper will be found in the appendix.

DISCUSSION.

Mr. Alderman Buckley said that he did not wish to question the value of the statistics or the accuracy of the experiments, yet he was somewhat disappointed that the author had not been able to give them such information as would enable them to overcome the serious difficulties in connection with bearings that arise in every day practice. Before proceeding however he wished to point out, respecting the position the author took up relative to the wearing of bearings laterally or vertically, that it was entirely forgotten by him that a shaft was a roller, and that a roller in whichever direction it turned would wear upon that side, unless it was reversed by gearing or other mechanical appliances. As an illustration, he thought that if the side brasses of a bearing were removed the shaft would roll out, and therefore the proposed construction of pedestal would be quite inapplicable to the case of a mill engine or shaft.

As regards lubrication, he did not hesitate to say that it was a subject of the greatest importance, and particularly at the present time, when the magnitude of the mills being built and the high speed at which engines were running, were taken into consideration In his mind there was no greater problem upon which it was desirable that the members of that Association

should endeavour to solve, than the best methods of lubricating under varied conditions, and if each would at some future time state their experiences in that matter, he thought it would be of great benefit to all concerned.

Pedestals he believed during the last 20 years had been made in every possible form which could be conceived, with more or less modifications and improvements, though speaking for himself, after a long experience, he did not think that the present practice was much in advance of what it was 30 years ago. In making such an assertion he did not say that there were not good pedestals of special types, but rather that there was a lack of them for different applications, as of course what was suitable for one purpose did not suit another. He was of opinion that as much importance attached to the proper application of a bearing as to its general construction. A great many contrivances had been made by more or less eminent engineers for the purpose of getting lubricated matter underneath heavy shafts, and it was upon this he thought the author might have alluded to in his paper. Recently he had had a case of a bearing 10in. or 12in. diameter by 2ft. 6in. long, with a heavy weight upon the shaft, and the difficulty of overheating had been overcome by cutting in the journal, at different points, three recesses or grooves, each one third the length of neck at equal distances in the circumference; these three cavities fill with oil every time the shaft goes round, and thus feed the whole of the bearing. He had adopted this method in subsequent cases, and had found it to work satisfactorily in every respect.

Mr. Hans Renold remarked that he had listened to the paper with much pleasure, and was of opinion that the author had done good work, if only by directing attention to this important question. On the other side of the Atlantic a large amount of attention was now being given to the subject with remarkable results, and it behoved English engineers to seriously consider the lubrication of bearings, both large and small.

Mr. John Taylor observed that the subject under discussion was a most important one, and in his opinion could only be

dealt with from a practical point of view. He was sorry more had not been said regarding the continuous feed pedestal, which had been made by one firm in Manchester for many years with the greatest success.

In a great many cases of heating in heavy journals, he thought that as a rule the brasses had been made too thin, and bending up so as to clip the shaft, the lubricant was scraped off and thus caused overheating.

As regarded the pad system of lubrication he did not think it way in any way a new idea, as it had been in use for the last thirty years.

In the construction of efficient pedestals and bearings it was essentially necessary that they should contain a liberal quantity of metal, but unfortunately in a many cases manufacturers would not pay the price necessary for good work, and consequently engineers had to yield to what might be termed the competitive position.

In conclusion, he could only say that the whole subject of lubrication was worthy the consideration of the members of that Association, as in his opinion no other body of men could deal with it from a more practical point of view.

Mr. Jos. Nasmith differed from the opinions expressed by one or two previous speakers, and ventured to think that the paper before them would repay a considerable amount of attention, and would afford some of them who had not so wide an experience as some of the previous speakers very valuable information. It should never be forgotten, he thought, that experiments on lubrication must necessarily be conducted on small shafts. Of course it was impossible to take a crank shaft of an engine of 1,000 horse-power, and put it in a testing machine, but the question arose whether in experimenting properly with smaller bearings, sufficiently good results were not obtained to enable them to solve the problem of efficient lubrication in larger bearings. It was from this point of view, he thought, in which they should consider the author's paper. As an instance of what he meant, he might point out that the instance given by Alderman Buckley of cutting away and recessing the neck

of a journal, practically bore out Professor Goodman's assertion that bath lubrication was the most perfect method.

He thought the whole of the author's conclusions were perfectly sound, and that when Messrs, Buckley and Taylor came to read the paper, they would find there was more in it than appeared to them that evening.

He might point out that the Mohler pedestal and the universal bearings which were largely used in the United States, were successful instances of continuous lubrication, but he was of opinion that one of the greatest corroborations of the author's remarks on the lasting power of oil, and the fact that it can be used a long time without detriment to bearings, was found in the quick running spindles used in ring frames. These revolved 9,000 times a minute, and ran from six to nine months with one small charge of oil, the abrasion being very slight in that period.

The question of lubrication was not merely that of lubricating the crank shaft of large engines, but also of lubricating the line shafts in mills. If Professor Goodman's experiments only resulted in calling the attention of steam users in this country to the necessity of adopting the best form of bearing for the line shafting within their mills, and consequently of minimising the waste of oil, then he thought they would have achieved a useful purpose.

Mr. T. Daniels thought the author had very ably dealt with his subject, and he would suggest that in again making experiments with Stroudley's machine, that he should cut a groove round the bearing, as he believed it would greatly help to lubricate the off side of the brass. It had been customary for many years to cut spiral grooves round the necks of shafts, and therefore he was a little surprised to learn that Alderman Buckley had only recently adopted the practice. He might add that they were unable to get the worm on Sellar's planing machine to work satisfactorily until they adopted the bath principle of lubrication.

As regarded the Stroudley machine, it was just the kind of machine which Mr. Stroudley would require to test the bearings

of locomotives. He remembered in Mr. Connell's time that they used to put sponge in the axle box keeps to lubricate the journals on the under side, and it was found if the brasses of the axle boxes were bored too large, a knock in the journal was developed.

Mr. A. Rea thought the subject was of the greatest importance, and that the author had dealt with it in a most satisfactory manner. He had known cases where out of total power of 1,000 or 1,200 horse-power, the friction diagram represented 170 to 200 horse-power.

It could not be denied he continued, that taking mills generally, there was an enormous loss of power and energy through friction and inefficient lubrication; engineers, however, could not necessarily be blamed for such loss, since in a many cases, it was due to the mill owners not paying enough for efficient work. He was thoroughly convinced that if mill owners would employ an engineer to make periodical dynamometer tests of their machines and journals, losses ocurring through friction would be detected.

As regarded pad lubrication, he was not much in favour of it, as dust accumulated in the pads and caused abrasion of the shafts. On the contrary, he approved of the principle of bath lubrication, and when dealing with the bearings of large shafts, he made the brasses square on the outside, and cut out grooves in the corners, thus providing space for the oil. In his opinion every engineer should endeavour to reduce the weight on the journal to the lowest possible limit. As an instance of the possibility of perfectly lubricating sliding surfaces, he might mention that he had an engine under his charge which had been running since 1884 weekly, from Monday morning to Saturday evening, the slide block of which had not yet touched the surface of the guides.

Mr. E. Marshall observed that his experience showed him that to cut away the brasses as suggested was quite feasible, and tended to preserve the shaft. He had an upright shaft working, the footstep of which had not seen the light of day since 1867, and had not in that time worn down $\frac{1}{8}$in.

Mr. Alderman Buckley explained that he did not advocate a tight fitting bearing, and said that it was a common practice to counterbore steps, side bearing being an evil except in the cases of gearing where there was side pressure. As regards the alleged superiority of the Americans in this subject, referred to by Mr. Renold, he might say that if that gentleman would come to Oldham, he would show him a pair of necks 14in. in diameter by 2ft. 3in. long, on a shaft making 54 revolutions, and developing 1,100 horse-power, the oil consumption of which was only one pint per week, and evaporation came even out of that small quantity. If better results than this could be shown in America, he should like to have particulars of such cases.

Mr. E. G. Constantine said that Professor Goodman's remarks were all borne out by the most most modern marine practice. Some years ago he had the doubtful pleasure of holding the position of an engineer on board a large Atlantic liner, and in one of the trips westward the low pressure crank pin gave a large amount of trouble through heating, After a time several flaws developed in the surface of the pin, and in order to ascertain the extent of the failure, the pin was grooved with a round-nosed chisel ; after that the pin gave little or no trouble, the groves evidently assisting in distributing the lubricant.

Professor Goodman in replying, said that in spite of one or two adverse remarks, the remainder of the speakers had contributed most valuable information by their remarks, and he thanked them very much for the complimentary terms in which they had referred to his paper.

In reply to Mr. Buckley, who was somewhat disappointed because the paper did not go beyond the ordinary practice of the present day, the author would ask, What is the ordinary practice of the present day? Take Mr. Alderman Buckley's own practice in the case he cited—semi-circular brasses and syphon lubrication—he stated that his bearings continually bothered him through heating. Was such a result to be wondered at ? The paper certainly advocated something in advance of this, in fact it most strongly condemned such a practice as he spoke

of. The brass in question carried a load of 30 tons, hence the pressure was about 200lbs. per square inch, a mere bagatelle to the pressures referred to in the paper ; and many brasses that the author had constructed were carrying, and had for years carried far greater loads without ever running hot, and moreover they used an exceedingly small quantity of oil. Many chronic cases of hot bearings had been permanently cured by adopting the author's system.

In the matter of the side on which brasses wear, it was quite beyond dispute that the shaft did *not* act as a roller, and that the wear did *not* occur in the way in which Mr. Buckley thought it did. In running such friction testing machines as the "Stroudley" or "Tower," the *apparent* frictional resistance would gradually become zero, in fact less than zero if the machine be allowed to run for a considerable time without attention ; by examining their construction it would be seen that that action most clearly proves that the wear is on the "off" side. The author had in his possession several letters received from the late Mr. Stroudley, in which that gentleman distinctly stated that he had observed the same action in locomotive and marine practice.

If however the brasses loosely fit the shaft, then the case was totally different.

The author entirely agreed with Mr. Buckley that the practice of the present day was but little, if any, in advance of what it was 30 years ago. In fact this is precisely the author's excuse for bringing this subject before the Association. But it is somewhat discouraging to him to have pointed out the results of the most recent experiments, and then to find that they are not understood or appreciated, especially when both practice and science unmistakably indicate the directions in which improvements must be made.

Mr. Stroudley writing on "The bearing of a carriage axle" (*carriage* not locomotive. J. G.), says, "the bearing and wheel are propelled forward by the brass, the greatest pressure coming upon the after portion; and yet, strange to say, the wear takes place on the forward side; that is, the axle wears forward instead of backward, as might have been expected. This has been observed for many years, but I am not sure that the cause has been clearly comprehended, and I think you would do well to write some notes upon it."

P.S.—"This has also been observed in large marine engine journals, which always wear the opposite way to what they might be expected to."

In condemning the author's system of applying pads to plummer blocks, Mr. Taylor must remember that in doing so he was condemning the practice of all our most brilliant and leading locomotive engineers, for they, to a man, adopt the pad system of lubricating.

It was quite unnecessary for him to have reminded the author that pads were used "thirty years ago," for he was perfectly well aware that they then did, and have ever since done good service, and what he now urges is an extension of that system to bearings of every description ; and he would like to ask were there half a dozen, or even were there three firms in this country who use pads on bearings for machinery ? In the case of one firm of gas engine makers who had adopted the author's system, the mechanical efficiency of the engine came out *over ninety per cent.* when tested by a leading London engineer, who further remarked that the amount of lubrication used was very small indeed.

The remark that the design of bearing shown was not suitable for shafts on which there was a side thrust, would surely not have been made had the speaker considered for one moment the words of the paper in which it said that the resultant line of pressure on the bearing must pass through the centre line of the brass.

Again, Mr. Taylor's remarks on the danger arising from brasses pinching-in at the sides, simply added further evidence as to the soundness of the principle advocated by the author, viz., that of cutting away the sides of the brass, for it required but little argument to prove that if there be no sides, then no sides could pinch-in.

Mr. Rea referred to the clogging of pads. The author must admit that there was much force in his argument, if the old-fashioned vegetable lubricants be used, but such an objection did not apply now that vegetable lubricants were becoming obsolete, and that high-class mineral oils were rapidly taking their place, which not only lubricated better, but did not clog and cost less than one half of the former. Asbestos pads might be used when risk of fire had to be specially guarded against.

Mr. Nasmith had referred to the size of the testing machines; the great difficulty in using a large machine was that the loads must be applied by dead weights and not by levers, the weights becoming of very inconvenient dimensions when they amount to many tons. The machine on which most of the author's experiments were made was by no means a "toy," the axle was 7in. diameter, and was loaded up to ten tons.

Mr. Daniels' remarks on spiral oil grooves were most interesting; the author would certainly make the suggested experiments when an opportunity occurred. There was no objection whatever to oil holes and oil grooves as long as they did not lie along the axis of resultant pressure; if, however, such a state of affairs should occur, the bearing would not retain the oil on the crown just where it was most required.

In conclusion, he could only say that if his paper should have the effect of causing more attention to be given to this important question, he should feel amply repaid for his efforts.

On the motion of the Chairman, seconded by Mr. Ashbury, a cordial vote of thanks was passed by acclamation to Professor Goodman for his able paper, to which he briefly responded, and the proceedings closed.

APPENDIX.

A much closer approximation for the laws of dry surfaces is given by the following formulæ:—

Let P = the total pressure normal to the surfaces.
u = the co-efficient of friction.
R = the frictional resistance in lbs.
S = the velocity of sliding in feet per minute.
K = a constant to be determined by experiment in each case.

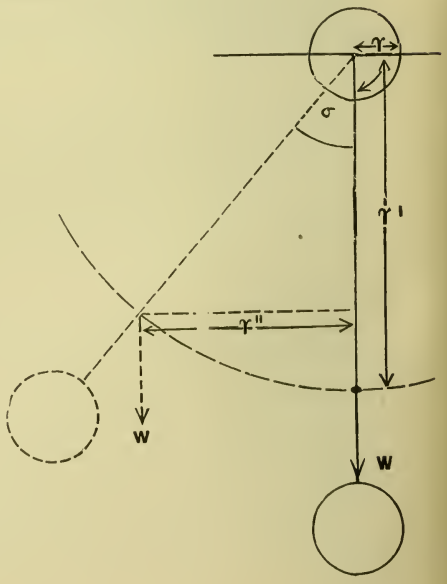
$$R = \frac{P^{1\cdot1}\sqrt{P}}{K}$$ For pressure and frictional resistance.

or
$$u = \frac{K}{2\cdot4\sqrt{S}}, \quad R = \frac{PK}{2\cdot4\sqrt{S}}$$ For velocity and frictional resistance.

The co-efficient of friction of the various machines is found thus:—

THURSTON.

Let r^1 = radius of the c. of g. of pendulum.
r = radius of journal.
W = weight of pendulum.
l = length of journal.
P = Total pressure on journal in pounds.
P^1 = pressure on journal due to spring.
p = total pressure per square inch.
σ = angle pendulum makes with the vertical.
u = co-efficient of friction
R = frictional resistance.



Then $R r = W r_{''} = W r^1 \sin \sigma$ (1)

$$R = \frac{W r^1 \sin \sigma}{r} \quad (2)$$

$$u = \frac{R}{P} = \frac{W r^1 \sin \sigma}{P r} \quad (3)$$

$$p = \frac{P}{4 l r} = \frac{2 P^1 + W}{4 l r} \quad (4)$$

$$u = \frac{R}{4 p l r} \quad \text{from (3) and (4)} \quad (5)$$

$$R = 4 u p l r = \frac{W r^1 \sin \sigma}{r} \quad \text{from (2) and (5)}$$

$$u = \frac{\frac{W r^1 \sin \sigma}{r}}{4 p l r} = \frac{W r^1 \sin \sigma}{4 p l r^2} = \frac{W r_{''}}{P r}$$

W, r^1, l, r are all known for any given machine.
σ is measured from the scale reading on P P (fig. 1).
p ,, ,, ,, H H ,,

TOWER'S MACHINE.

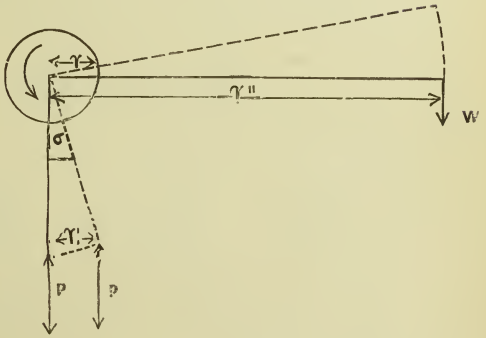
When working with a scale-pan and measuring W, $R r = W r$

$$\frac{R}{P} = u = \frac{W r_{''}}{P r}$$

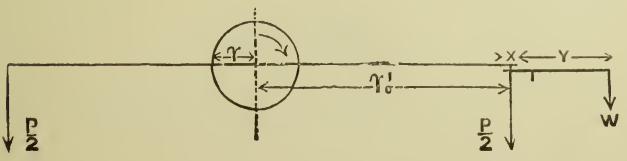
or when working with a pointer and measuring σ

$$R r = P r^1_1$$

$$\frac{R}{P} = u = \frac{r^1_1}{r}$$



STROUDLEY'S MACHINE.



The system of levers gives $r_{''}$ (page 119 in Tower's machine)

$$r_{''} = \frac{r \frac{1}{0} y}{x}$$

$$R\,r = W\,r_{''} \qquad R = \frac{W\,r_{''}}{r}$$

$$\frac{R}{P} = u = \frac{\frac{W\,r''}{r}}{P} = \frac{W\,r_{''}}{P\,r}$$

$r_{''}$ and r are both constant for any given machine, then when P is known W gives the co-efficient of friction.

TABLE I. (*a.*)

BATH LUBRICATION.

Showing the effect of pressure on frictional resistance.

Selected from Mr. Tower's results.*

Nominal load per square inch, pounds.	100	153	205	310	415	520
Frictional resistance in pounds per square inch.	0·45 0·42 0·50 0·67	0·46 0·41 0·49 0·63	0·43 0·41 0·47 0·63	0·46 0·43 0·53 0·68	0·49 0·49 0·58 0·66	0·42 0·47 0·52 0·67

Selected from the Author's experiments.

Total load in lbs.	100	150	200	300	400	500
Frictional resistance in pounds.	2·38 2·09 0·84 0·67	2·40 2·10 0·84 0·67	2·42 2·12 0·84 0·68	2·43 2·13 0·84 0·72	2·48 2·16 0·84 0·72	2·45 2·20 0·84 0·75

The relation between the frictional resistance and pressure with bath lubrication is fairly well represented by the following formula, using the same notation as before :—

$$F = \frac{P + 10{,}000}{K}$$

* Institution of Mechanical Engineers' Proceedings, 1883.

TABLE I. (*b.*)

Mechanical efficiency of the experimental Steam Engine at University College, London.

Illustrating the constancy of the frictional resistance under light and heavy loads. The engine was kept thoroughly well lubricated. Revolutions 100 per minute.

Brake Horse-power.	Indicated Horse-power.	Horse-power used in driving Engine.
0	2·75 (Mean	2·75
2·25	5·22 of 4)	2·97
5·32	9·34	4·02
5·40	9·63	4·17
5·63	9·25	3·62
5·66	8·99	3·33
5·70	10·44	4·74
6·89	10·47	3·58
7·50	10·23	2·73
7·57	11·11	3·54
7·66	11·10	3·44
7·66	11·14	3·48
7·77	10·78	3·01
9·09	12·34	3·25
9·63	12·16	2·53
11·04	14·06	3·02
11·09	13·95	2·86
11·21	14·07	2·86
11·25	14·29	3·04

TABLE II.

PAD LUBRICATION.

Showing the effect of pressure on the frictional resistance of imperfectly lubricated surfaces.

Mr. Stroudley's experiments.

Load on brass in pounds per square inch.	237	251	293	333
Frictional resistance.	1·70	1·93	2·34	2·64

TABLE II.—*Continued.*

Selected from the Author's experiments.

Total load on brass pounds.	100	150	200	250	300	400	500
Frictional resistance in pounds.	3·06 2·10 4·77 2·58	3·27 2·14 5·46 3·02	3·48 2·20 6 02 3·36	3·77 2·25 6·58 3·65	4·02 2·40 7·14 3·84	4·52 2·68 7·64 4·32	4·85 3·05 7·85 4·75

Selected from Mr. Tower's experiments.

Total load on brass pounds.	100	153	205	258	275	310	328
Frictional resistance in pounds.	1·09 1·23 1·33	1·47 1·56 1·61	1·78 1·74 1·61	2·44 2·28 2·17	2·49 2·62 2·84	3·06 2·84 3·06	3·50 3·35 3·21

The following formulæ approximately shows the relation between frictional resistance and pressure when the lubrication is imperfect:—

$$F = \frac{P + 500}{K} \qquad \text{(Saturated Pad.)}$$

$$F = \frac{P + 50}{K} \qquad \text{(Ordinary Pad.)}$$

TABLE III.

Showing the effect of velocity on the frictional resistance.

Below 100 feet per minute.

Selected from the Author's experiments.

							Nominal load per sq. inch.
Feet per minute. Co-eff. of friction	4·7 0·119	8·9 0·091	14·14 0·074	30·4 0·039	85·3 0·014	103·7 0·014	150lbs.
Feet per minute. Co-eff. of friction	6·3 0·119	8·9 0·077	15·2 0·046	45·6 0·016	79·6 0·013	100 0·011	75lbs.
Feet per minute. Co-eff. of friction	5·24 0·095	9·95 0·059	14·66 0·042	16·23 0·026	63·9 0·018	100·5 0·018	50lbs.

TABLE III—*Continued.*

Showing the effects of velocity on the frictional resistance.

Below 100 feet per minute.

Mr. Wellington's experiments.*

Feet per minute.	0+	2·16	3·33	4·86	8·82	21·42
Co.eff. of friction	0·118	0·094	0·071	0·068	0·055	0·047
Feet per minute.	35·37		53·01	89·28		106·02
Co-eff. of friction	0·040		0·035	0·030		0·026

Prof. Kimball's experiments.†

Feet per minute.	1	3	5	7	10	15
Co-eff. of friction	0·150	0·122	0·114	0·093	0·079	0·066
Feet per minute.	20	30	40	60	80	100
Co-eff. of friction	0·058	0·054	0·053	0·052	0·051	0·050

Above 100 feet per minute.

Mr. Tower's experiments.

Feet per min	209	262	314	366	419	471	Nomimal load per square inch.
Co-efficient of friction.	0·0010 0·0013 0·0014	0·0012 0·0014 0·0015	0·0013 0·0015 0·0017	0·0014 0·0017 0·0019	0·0015 0·0018 0·0021	0·0017 0·0020 0·0024	520lbs. 468lbs. 415lbs.

* Transactions of the American Society of Civil Engineers, 1884. Vol. XIII., p. 409.

† American Journal of Science. March, 1878. Page 194

TABLE IV.

Showing the temperature, viscosity, velocity and load per square inch when the brass on the Author's machine began to show signs of seizing.

Temperature Fah.	Viscosity, taking Rape at 60° as 100.	Revolutions per min.	Load per square inch.
68°	160	15	134
81°	115	15	125
90°	85	15	125
104°	60	15	75

TABLE V.

Showing the relation between frictional resistance and temperature.

Selected from Mr. Tower's experiments (Lard Oil).

Temp. in deg. Fah.	60°	70°	80°	90°	100°	110°	120°
Co-efficient of friction.	·0059 ·0084 ·0103	·0048 ·0065 ·0080	·0040 ·0052 ·0063	·0034 ·0043 ·0052	·0029 ·0037 ·0045	·0026 ·0032 ·0039	·0024 ·0029 ·0035
Prob. Viscosity Rape at 60° being 100	89	75	65	55	48	40	35

Selected from the Author's experiments (Rape Oil).

Temp. in deg. Fah.	60°	70°	80°	90°	100°	110°	120°
Co-efficient of friction.	0·017 0·014 0·0128 0·0176	0·016 0·012 0·0112 0·0136	0·015 0·0104 0·0096 0·0112	0·014 0·0090 0·0080 0·0092	0·012 0·0072 0·0064 0·0074	0·010 0·0056 0·0048 0·0060	.. 0·0044 0·0040 0·0048

TABLE VI. (Fig. 6A.)

Speed Trials. Syphon Lubrication.

Temperature 40° Load 300lbs.

Chord.. 1·25in. Angle..			1·0in.			0·5in.		
Revs.	Ft. min.	*u*.	Revs.	Ft. min.	*u*.	Revs.	Ft. min.	*u*.
362	189·5	·0350	379	198·5	·0189	367	192·2	·0210
303	158·7	·0280	350	183·3	·0154	309	161·8	·0175
257	134·6	·0245	268	140·4	·0126	262	137·2	·0161
233	122·0	·0203	231	121·0	·0112	198	103·7	·0140
192	100·5	·0182	152	79·6	·0126	163	85·3	·0140
163	85·3	·0182	87	45·6	·0161	58	30·4	·0385
122	63·9	·0182	29	15·2	·0462	27	14·14	·0735
28	14·66	·0420	17	8·9	·0770	17	8·9	·0910
31	16·23	·0245						
19	9·95	·0595	12	6·3	·119	9	4·7	·1190
10	5·24	·0945						

TABLE VII. (Fig. 7.)

SATURATED PAD.

Revolutions 15. Brass 4in. × 1in.

Load.	Temp. 40° C.		32·5°		27°		20°	
	u.	F. R.	*u*.	F. R.	*u*.	F. R.	*u*.	F. R.
50	·0071	·35	·0076	·38	·0076	·38	·0099	·49
100	·0038	·38	·0040	·40	·0042	·42	·0050	·50
150	·0028	·42	·0025	·37	·0028	·42	·0035	·52
200	·0021	·42	·0019	·38	·0021	·42	·0026	·52
250	·0017	·42	·0017	·42	·0017	·42	·0021	·52
300	·0021	·63	·0021	·63	·0014	·42	·0019	·57
350	·0030	1·05	·0018	·63	·0012	·42	·0018	·63
400	·0042	1·68	·0021	·84	·0010	·40	·0021	·84
450	·0084	3·78	·0018	·81	·0013	·58	·0030	1·35
500	·0231	11·55	·0042	2·10	·0034	1·70	·0046	2·30
520			·0178	9·26				
550	·0649	35·69	·0435	23·9	·0262	14·41	·0084	4·62
570	·0810	46·17						
580	·0869	50·40						

Note the effect of temperature on the change point.

For full details of these and the following Tables, with corresponding figures, see the author's Paper, Proceedings I.C.E. Vol. lxxxix., p. 421.

TABLE VII.

OIL BATH.

Temperature 40°			Temperature 30°		Temperature 20°	
Load.	*u*.	F. R.	*u*.	F. R.	*u*.	F. R.
50	·0061	·30	·0080	·40	·0084	·42
100	·0038	·38	·0041	·41	·0042	·42
150	·0027	·40	·0028	·42	·0028	·42
200	·0020	·40	·0021	·42	·0021	·42
250	·0016	·40	·0021	·52	·0019	·47
300	·0017	·51	·0017	·51	·0016	·48
350	·0021	1·22	·0015	·52	·0014	·49
400	·0029	1·16	·0016	·64	·0013	·52
450	·0042	1·89	·0019	·85	·0013	·58
500	·0189	9·45	·0044	2·20	·0029	1·45
550	·0515	28·33	·0126	6·93	·0764	42·03
560	·0562	31·48	·0142	7·95	·0937	52·47
580	·0724	42·00	·0253	14·68	·1086	63·00

Note the influence of temperature on the change point.

TABLE VIII. (Figs. 8 & 9.)

SPEED TRIALS.

Load 300lbs. Temperature 40° C. Brass 4in. × 2in.

Revs. per min.	Saturated Pad.		Bath.		
	Ft. per min.	*u*.	Revs. per min	Ft. per min.	*u*.
20	10·5	·0021	9	4·7	·0035
23	12·0	·0028	12	6·3	·0035
66	34·5	·0091	20	10·5	·0035
76	39·8	·0098	23	12·0	·0036
105	55·0	·0161	140	73·3	·0098
125	65·4	·0182	158	82·7	·0119
152	79·6	·0231	169	88·5	·0126
175	91·6	·0252	204	106·8	·0147
192	100·5	·0280	216	113·1	·0150
210	110·0	·0294	261	136·7	·0157
233	122·0	·0315	292	152·9	·0168
303	158·7	·0343	321	168·1	·0182
315	164·9	·0350	362	189·5	·0206
			460	240·8	·0252

TABLE IX. (Figs. 8, 9, 10.)

SPEED TRIAL.

Load 300lbs. Temperature 40° C. Brass 4in. × 1·5in.

Bath.			Saturated Pad.			Pad.		
Revs. min.	Feet min.	*u.*	Revs. min.	Feet min.	*u.*	Revs. min.	Feet min.	*u.*
21	11·0	·0010	10	5·2	·0014	15	7·8	·0014
29	15·2	·0014	20	10·5	·0021	21	11·0	·0017
109	57·1	·0038	29	15·2	·0024	111	58·1	·0091
181	94·8	·0056	105	55·0	·0070	175	91·6	·0126
193	101·0	·0059	140	73·3	·0084	198	103·7	·0140
233	122·0	·0070	175	91·6	·0112	233	122·0	·0168
303	158·6	·0091	204	106·8	·0119	268	140·3	·0196
338	177·0	·0105	210	110·0	·0133	303	158·6	·0231
362	189·5	·0112	251	131·4	·0154	373	195·3	·0273
			280	146·6	·0168	443	231·9	·0322
			344	180·1	·0189			
			379	198·4	·0203			

TABLE IX. (Figs. 8 & 9.)

SPEED TRIAL.

Load 300lbs. Temperature 40° C. Brass 4in. × 1·75in.

Bath.			Saturated Pad.			Pad.		
Revs. min.	Feet min.	*u.*	Revs. min.	Feet min.	*u.*	Revs. min.	Feet min.	*u.*
8	4·2	·0007	10	5·2	·0014			
			15	7·8	·0021			
14	7·3	·0008	21	11·0	·0028			
128	67·0	·0035	150	78·5	·0147			
186	97·4	·0070	175	91·6	·0161			
			200	104·7	·0168			
233	122·0	·0080	240	125·6	·0192			
262	137·2	·0087	260	136·1	·0203			
268	140·3	·0087	265	138·7	·0206			
298	156·0	·0098	270	141·4	·0210			
368	192·7	·0108	300	157·1	·0238			

TABLE X. (Figs. 8, 9, 10.)

SPEED TRIAL.

Conditions as last. Brass 1·0in. × 4in.

Bath.			Saturated Pad.			Pad.		
Revs. min.	Feet min.	*u*.	Revs. min.	Feet min.	*u*.	Revs. min.	Feet min.	*u*.
8	4·2	·0042	17	8·9	·0007	6	3·1	·0210
11	5·7	·0007	23	12·0	·0014	8	4·2	·0070
18	9·4	·0007	105	55·0	·0035	11	5·7	·0035
30	15·7	·0010	146	76·4	·0042	15	7·8	·0035
70	36·6	·0021	163	85·3	·0056	70	36·6	·0042
163	85·3	·0028	204	106·8	·0063	175	91·6	·0070
233	122·0	·0038	257	134·6	·0077	210	110·0	·0091
303	158·6	·0042	315	164·9	·0084	233	122·0	·0119
362	189·5	·0063	338	177·0	·0098	268	140·3	·0147
						338	177·0	·0203
						367	192·1	·0231

TABLE X (*a*). (Figs. 8, 9, 10.)

SPEED TRIAL.

Conditions same as last. Brass 0·5in. × 4in.

Bath.			Saturated Pad.			Pad.		
Revs. min.	Feet min.	*u*.	Revs. min.	Feet min.	*u*.	Revs. min.	Feet min.	*u*.
5	2·6	·1610	9	4·7	·1610	10	5·2	·1540
15	7·8	·0630	15	7·8	·0910	15	7·8	·0560
21	11·0	·0140	26	13·61	·0700	21	11·0	·0021
30	15·7	·0052	73	38·2	·0021	33	17·3	·0021
109	57·1	·0017	169	88·5	·0024	52	27·2	·0028
128	67·0	·0017	213	111·5	·0028	117	61·3	0042
198	103·7	·0021	233	122·0	·0035	169	88·5	·0070
233	122·0	·0028	286	149·7	·0063	233	122·0	·0091
280	146·6	·0035	350	183·2	·0098	309	161·8	·0126
315	164·9	·0038	408	213·6	·0126	350	183·2	·0168
350	183·2	·0042				400	209·4	·0217
						464	242·9	·0252

TABLE XI. (Fig. 11.)

BATH LUBRICATION.

Temp. 40° C. Revols. 233 per min. Length of Brass, 4in. The loads and frictional resistances are the total amounts expressed in lbs. u==coefficient of friction.

SEMICIRCLE. Width of chord in contact, 2in. / Angle subtended, 180°...			1·75in. 122°		1·5in. 97°		1·0in. 60°		0·5in. 29°	
Total load.	u.	F. R.	u.	F. R.	u.	F. R.	u.	F. R.	u.	F. R.
50	·0441	2·20	·0458	2·29	·0418	2·09	·0210	1·05	·0126	·63
100	·0288	2·88	·0238	2·38	·0209	2·09	·0105	1·05	·0084	·84
150	·0192	2·88	·0160	2·40	·0140	2·10	·0070	1·05	·0056	·84
200	·0159	3·18	·0121	2·42	·0106	2·12	·0055	1·10	·0042	·84
250	·0128	3·20	·0097	2·42	·0085	2.12	·0044	1.10	·0034	·84
300	·0103	3·09	·0081	2·43	·0071	2·13	·0037	1·11	·0028	·84
350	·0085	2·97	·0070	2·45	·0061	2·13	·0033	1·15	·0024	·84
400	·0071	2·84	·0062	2.48	·0054	2·16	·0029	1·16	·0021	·84
450	·0062	2·79	·0055	2·47	·0049	2·20	·0028	1·26	·0019	·84
500	·0058	2·90	·0049	2·45	·0044	2·20	·0029	1·45	·0017	·84
550	·0051	2·85	·0045	2·47	·0040	2·20	·0027	1·48	·0015	·84
Mean.		2·89		2·42		2·14		1·18		·82

TABLE XII. (Fig. 12.)

SATURATED PADS.

Temperature 40° C. Revolutions 233. Same conditions as in Table XI.

Chord .....2in. Angle .....180°			1·75in. 122°		1·5in. 97°		1·0in. 60°		0.5in. 29°	
Load.	u.	F. R.	u.	F. R.	u.	F. R.	u.	F. R.	u.	F. R.
50	·0672	3·36	·0580	2·90	·0420	2·10	·0273	1·36	·0168	·84
100	·0388	3·88	·0306	3·06	·0210	2·10	·0152	1·52	·0084	·84
150	·0252	3·78	·0218	3·27	·0143	2·14	·0105	1·57	·0056	·84
200	·0199	3·98	·0174	3·48	·0110	2·20	·0079	1·58	·0044	·88
250	·0164	4·10	·0151	3·77	·0090	2·25	·0071	1·77	·0042	1·05
300	·0143	4·29	·0134	4·02	·0080	2 40	·0066	1·98	·0035	1·05
350	·0126	4·41	·0121	4·23	·0072	2·52	·0060	2·10	·0033	1·15
400	·0110	4·41	·0113	4·52	·0067	2·68	·0060	2·40	·0031	1·24
450	·0098	4·41	·0105	5·72	·0063	2 83	·0052	2·34	·0028	1·26
500	·0088	4·41	·0097	4·85	·0061	3·05	·0061	3·05	·0025	1·25
550	·0080	4·41	·0091	5·00	·0058	3·19	·0063	3·47	·0023	1·26
Mean.		4·47 see note.		3·98		2·49		2·10		1·06

NOTE.—The mean for the 2in. brass was found thus:—The mean of the first seven readings of the 2in. and 1¾in. gave a ratio of 1 : 1·124; then the correct mean for the 1¾in. brass was multiplied by this to get the correct mean for the 2in. brass; the last four readings of the 2in. are evidently incorrect. The same method has been adopted in other cases, but has always been noted.

TABLE XIII. (Fig. 13.)

PAD LUBRICATION.

Temperature 40° C. Revolutions 233. Same conditions as in Tables XI. and XII.

Chord.....2in. Angle .....180°			1·75in. 122°		1·5in. 97°		1·0in. 60°		0·5in. 29°	
Load.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.
50	·1120	5·60	·0849	4·24	·0819	4·09	·0462	2·31	·0420	2·10
100	·0635	6·30	·0477	4·77	·0488	4·88	·0258	2·58	·0220	2·20
150	·0455	6·82	·0364	5·46	·0357	5·35	·0201	3·02	·0154	2·31
200	·0370	7·40	·0301	6·02	·0283	5·66	·0168	3·36	·0126	2·52
250	·0315	7·87	·0263	6·58	·0227	5·67	·0146	3·65	·0105	2·62
300	·0285	8·55	·0238	7·14	·0196	5·88	·0128	3·84	·0094	2·82
350	·0250	8·75	·0212	7·42	·0171	5·99	·0120	4·20	·0081	2·83
400	·0225	9·00	·0191	7·64	·0152	6·08	·0108	4·32	·0076	3·04
450	·0200	9·00	·0173	7·79	·0142	6·39	·0101	4·54	·0072	3·24
500	·0185	9·25	·0157	7·85	·0136	6·80	·0095	4·75	·0065	3·25
550	·0165	9·09	·0143	7·87	·0128	7·04	·0095	5·23	·0061	3·25
Mean.		7·97		6·62		5·80		3·80		2·70

TABLE XIV. (Fig. 14.)

BATH LUBRICATION.

Temperature 20° C. Revolutions 15 per min.

Chord.....2in. Angle .....180°			1·75in. 122°		1·5in. 97°		1·0in. 60°		0·5in. 29°	
Load.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.
In lbs.										
50	·0147	·735	·0134	·67	·0127	·63	·0084	·42	·0080	·40
100	·0115	1·150	·0067	·67	·0062	·62	·0042	·42	·0041	·41
150	·0070	1·050	·0045	·67	·0042	·63	·0028	·42	·0028	·42
200	·0063	1·260	·0034	·68	·0031	·63	·0021	·42	·0031	·63
250	·0050	1·250	·0028	·70	·0025	·62	·0019	·47	·0029	·72
300	·0031	·930	·0024	·72	·0021	·63	·0016	·48	·0049	1·47
350	·0027	·945	·0020	·70	·0018	·63	·0014	·49	·0480	16·81
400	·0021	·840	·0018	·72	·0016	·64	·0013	·52	·0577	23·08
450	·0016	·720	·0016	·72	·0015	·67	·0013	·58	·0700	31·5
500	·0013	·650	·0015	·75	·0013	·65	·0029	1·45	·0766	38·3
550	·0011	·605	·0013	·71	·0012	·66	·0764	42·03	·0954	52·48
Mean.		·92		·70		·64		·48		·47

The inserted line shows the position of the change point, all readings below are neglected.

Mean of 9 readings ·63

Mean of 9 readings ·47

Mean of 3 readings ·42

Mean of 3 readings ·41

TABLE XV. (Fig. 15).

SATURATED PAD.

Temperature 20° C. Revolutions 15 per minute.

Chord .....2in. Angle .....180°			1·75in. 122°		1·5in. 97°		1·0in. 60°		0·5in. 29°	
Load.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.
In lbs.										
50	·0178	·89	·0157	·78	·0126	·63	·0092	·46	·0084	·42
100	·0105	1·05	·0080	·80	·0064	·64	·0046	·46	·0042	·42
150	·0073	1.09	·0055	·82	·0042	·63	·0031	·46	·0028	·42
200	·0058	1·16	·0044	·88	·0034	·68	·0023	·46	·0021	·42
250	·0046	1·15	.0036	·90	·0028	·70	·0018	·45	·0017	·42
300	·0038	1·14	·0031	·93	·0024	·72	·0015	·45	·0015	·45
350	·0033	1·15	·0027	·94	·0021	·73	·0013	·45	·0015	·52
400	·0030	1·12	·0025	1·00	·0019	·76	·0011	·44	·0016	·64
450	·0027	1·21	·0023	1·03	·0017	·76	·0011	·49	·0021	·94
500	·0024	1·20	·0021	1·05	·0016	·80	·0013	·65	·0031	1·55
550	·0023	1·26	·0019	1·04	·0015	·82	·0802	44·1	·0046	2·53
Mean.		1·13		·92		·72		·48		·46

All readings below the inserted lines are neglected.

Mean of 7 readings ·69 | Mean of 7 readings ·46 | Mean of 7 readings ·44

TABLE XVI. (Fig. 16.)

PAD LUBRICATION.

Temperature 20° Revolutions 15 per minute.

Chord.....2in. Angle			1.75in.		1·5in.		1·0in.		0·5in.	
Load.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.
50	·0266	1·33	·0199	·99	·0171	·85	.0099	·49	·0097	·48
100	·0154	1·54	·0106	1·06	·0088	·88	·0050	·50	·0048	·48
150	·0108	1·62	·0075	1·12	·0059	·88	·0035	·52	·0032	·48
200	·0087	1·74	·0059	1·18	·0045	·90	·0026	·52	·0024	·48
250	·0075	1·87	·0049	1·22	·0036	·90	·0021	·52	·0019	·47
300	·0065	1·95	·0042	1·26	·0030	·90	·0019	·57	·0016	·48
350	·0059	2·06	·0037	1·29	·0025	·87	·0018	·63	·0014	·49
400	·0055	2·20	·0034	1·36	·0023	·92	·0021	·84	·0012	·48
450	·0051	2·29	·0031	1·39	·0022	·99	·0030	1·35	·0016	·72
500	0049	2·45	·0029	1·45	·0021	1·05	·0046	2·30	·0029	1·45
550	·0047	2·58	·0027	1·48	·0021	1·15	·0084	4·62	·0072	3·96
Mean.		1·78		1·25		·94		·57		·51

All readings below the inserted lines are neglected.

Mean of 7 readings ·88 | Mean of 7 readings ·53 | Mean of 7 readings ·48

TABLE XVII.

SYPHON LUBRICATION.

Temperature 40° Revolutions 233.

Chord.....1·5in. Angle	1·25in.		1·0in.		0·5in.	
Load.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.
In lbs.								
50	·1148	5·74	·0840	4·20	·0756	3·78	·0420	2·10
100	·0651	6·51	·0504	5·04	·0420	4·20	·0252	2·52
150	·0457	6·85	·0371	5·57	·0287	4·31	·0189	2·83
200	·0346	6·92	·0288	5·76	·0225	4·50	·0173	3·46
250	·0277	6·92	·0231	5·77	·0180	4·50	·0168	4·20
300	·0231	6·93	·0192	5·76	·0150	4·50	·0196	5·88
350	·0198	6·93	·0168	5·88	·0129	4·52	·0180	6·30
400	·0175	7·00	·0154	6·16	·0112	4·48	·0199	7·96
450	·0162	7·29	·0137	6·17	·0100	4·50	·0196	8·82
500	·0147	7·35	·0126	6·30	·0101	5·05	·0181	9·05
550	·0139	7·64	·0116	6·38	·0092	5·06	·0183	10·07
Mean.	·0357	6·92		5·72		4·49		3·20
					Mean of 5 readings	4·25	Mean of 5 readings	3·02

Note.—With the brass 0·5in wide the machine ran very unsteadily, with a strong tendency to seize, therefore all readings below 250 are rejected.

TABLE XVIII.

SYPHON LUBRICATION.

Bell's Asbestos Oil. Temperature 20° Revolutions 15.

Chord.....1·5in. Angle	1·25in.		1·0in.		0·5in.	
Load.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.
In lbs.								
50	·0420	2·10	·0420	2·10	·0231	1·15	·0231	1·15
100	·0267	2·67	·0231	2·31	·0157	1·57	·0178	1·78
150	·0210	3·15	·0189	2·83	·0126	1·89	·0287	4·30
200	·0168	3·36	·0157	3·14	·0094	1·88	·0315	7·30
250	·0138	3·45	·0142	3·55	·0080	2·00	·0420	10·50
300	·0115	3·45	·0129	3·87	·0066	1·98	·0595	17·85
350	·0099	3·46	·0180	6·30	·0063	2·20	·0690	24·15
400	·0089	3·56	·0399	15·96	·0055	2·20	·0761	30·44
450	·0079	3·55	·0518	23·31	·0049	2·20	·0863	38·84
500	·0076	3·80	·0571	28·50	·0044	2·20	·0903	45·15
550	·0072	3·96	·0615	33·83	·0042	2·31	·0879	48·35

The above results are so irregular, due to the imperfect method of lubrication, that it is impossible to get any reasonable approximations of the relative friction with the varying chords.

TABLE OF MEANS. (Fig. 16A.)

Mean results of the six preceding experiments.

Revolutions 233. Temperature 40° C.

Bath	2in.	1·75in.	1·5in.	1.0in.	0·5in.
Bath	2·89	2·42	2·14	1·18	0·82
Sat. Pad ..	4·47	3·98	2·49	2·10	1·06
Pad	7·97	6·62	5·80	3·80	2·70
Mean	5·11	4·34	3·48	2·36	1·53

Revolutions 15. Temperature 20° C.

Chord	2in.	1·75in.	1·5in.	1·0in.	0·5in.
Bath	0·92	0·70	0·64	0·48	0·47
Pad Sat. ..	1·13	0·92	0·72	0·48	0·46
Pad	1·87	1·25	0·94	0·57	0·51
Mean	1·31	0·96	0·77	0·51	0·48

Mean of the above means.

Chord	2in.	1·75in.	1·5in.	1·0in.	0·5in.
R. 223. T. 40°	5·11	4·34	3·48	2·36	1·53
R. 15. T. 20° ..	1·31	0·96	0·77	0·51	0·48
Mean	3·21	2·65	2·12	1·43	1·00

Relation between the width of a brass and the frictional resistance deduced from the above experiments :—

Let R = the frictional resistance found by experiment when the width of the brass = W.

R_1 = the frictional resistance when the width is = W_1

D = the diameter of the journal.

$$R_1 = R \left(4{\cdot}7 \frac{W_1 - W}{D}\right)$$

or expressed in a logarithmic form,

$$\text{Log. } R_1 = \log. R + 0{\cdot}671 \left(\frac{W_1 - W}{D}\right)$$

Example.—The frictional resistance of a semicircular brass on a 5in. shaft is found to be 8lbs. What would it be if the sides were cut away to reduce the width to 3in.?

$$\text{Log. } R_1 = \log. 8 + 0{\cdot}671 \left(\frac{3-5}{5}\right)$$
$$= 0{\cdot}903 + 0{\cdot}671 \ (-0{\cdot}4)$$
$$= 0{\cdot}635$$
$$R = 4{\cdot}31\text{lbs.}$$

TABLE XIX.

Load=58lbs. per square inch.

Lubricant.	Natural.		*u.* of rest after standing 16 hours.	Ratio of *u.* of rest to natural *u.*	Ratio of	
	u.	Temperature.			Natural *u.*	*u.* of rest.
Bell's Asbestos Oil	0·0084	34·0°C.	0·192	22·9	1·0	2·1
Price's Valve Oil. B thick	0·0252	50·0°	0·147	5·8	3·0	1·6
Price's Valve Oil. A viscous	0·0329	37·5°	0·1715	5·2	3·9	1·9
Bell's "Asbestoline" ..	0·0350	40·0°	0·190	2·6	4·2	1·0
(Hard Solid Grease) ..						

TABLE XX. (Fig. 28.)

Rudge Ball Bearing. White Neutral Oil.

Revolutions 19.			Revolutions 157.		Revolutions 350.	
Load.	*u.*	F. R.	*u.*	F. R.	*u.*	F. R.
lbs.		lbs.		lbs.		lbs.
10	·0060	·06	·0105	·10	·0105	·10
20	·0045	·09	·0067	·13	·0120	·24
30	·0050	·15	·0050	·15	·0110	·33
40	·0052	·21	·0052	·21	·0097	·39
50	·0054	·27	·0054	·27	·0090	·45
60	·0050	·30	·0055	·33	·0075	·45
70	·0049	·34	·0054	·38	·0068	·47
80	·0048	·38	·0062	·49	·0060	·48
90	·0050	·45	·0068	·61	·0060	·54
100	·0058	·58	·0069	·69	·0057	·57
110	·0054	·59	·0065	·71	·0060	·66
120	·0055	·66	·0075	·90	·0057	·68
130	·0058	·75	·0078	1·01	·0062	·81
140	·0056	·78	·0077	1·08	·0060	·84
150	·0060	·90	·0083	1·24	·0062	·93
160	·0075	1·20	·0081	1·29	·0058	·93
170	·0079	1·34	·0078	1·33	·0055	·93
180	·0079	1·42	·0078	1·40	·0053	·95
190	·0087	1·65	·0076	1·44	·0054	1·03
200	·0090	1·80	·0081	1·62	·0060	1·20

TABLE XXI.

Pale American Oil.

Revolutions 19.			Revolutions 157.	
Load.	*u*.	F. R.	*u*.	F. R.
In lbs.		In lbs.		In lbs.
10	·0075	·07	·0060	·06
20	·0075	·15	·0075	·15
40	·0071	·28	·0075	·30
60	·0070	·42	·0075	·45
80	·0071	·57	·0071	·57
100	·0073	·73	·0072	·72
120	·0071	·85	·0069	·83
140	·0072	1·01	·0067	·94
160	·0072	1·15	·0066	1·06
180	·0072	1·30	·0066	1·19
200	·0073	1·46	·0066	1·32

SPEED TRIAL.

Revs per min...	15	93	175	204	280	Load 200lbs.
u	·0073	·0046	·0037	·0034	·0030	
F. R. lbs.....	1·47	·93	·75	·69	·30	

Fig. 1.

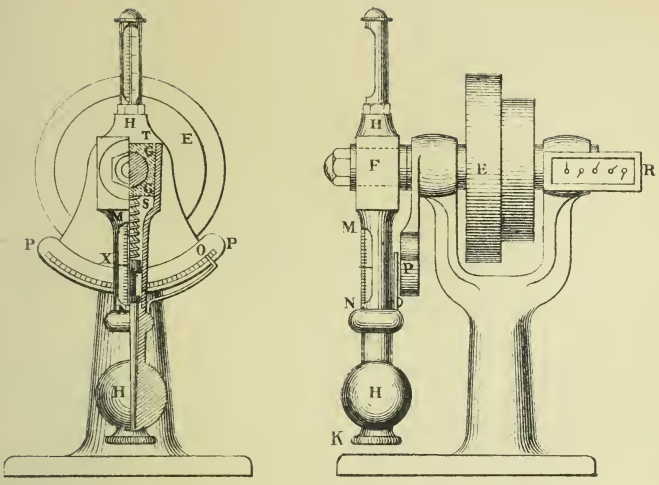


Fig 2.

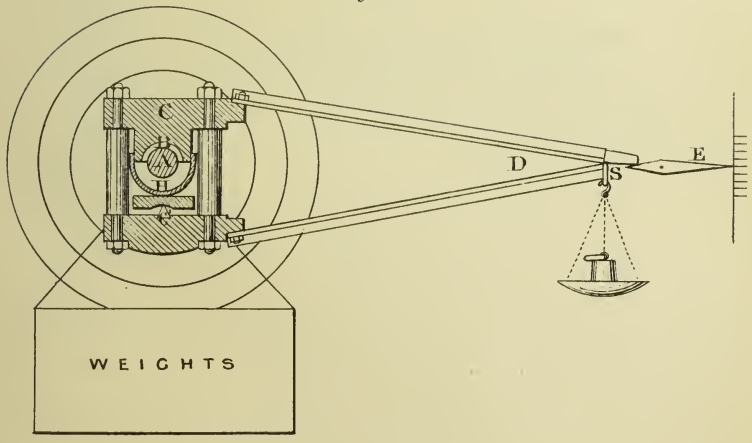


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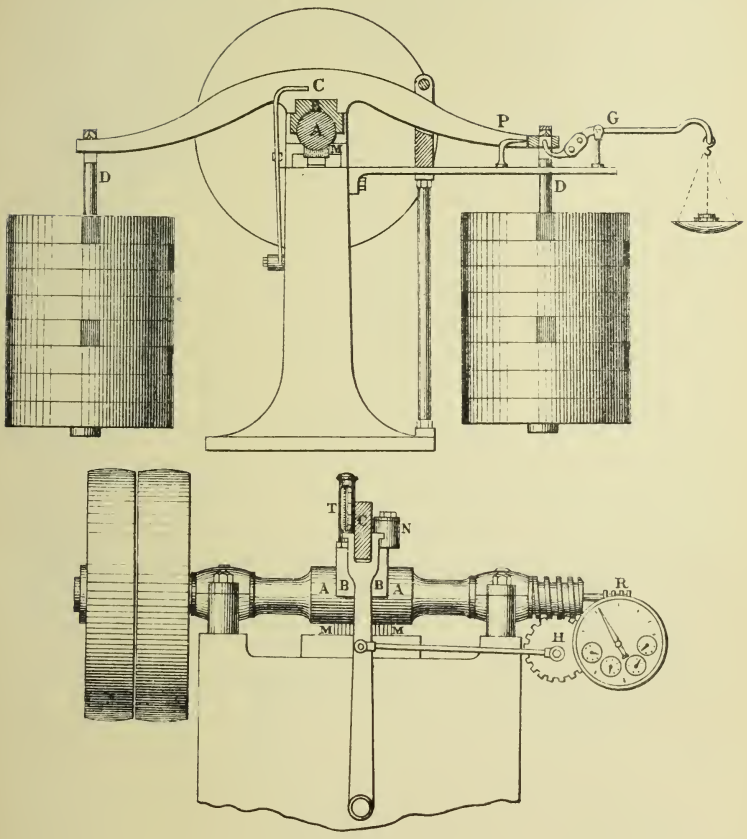
Fig. 3.



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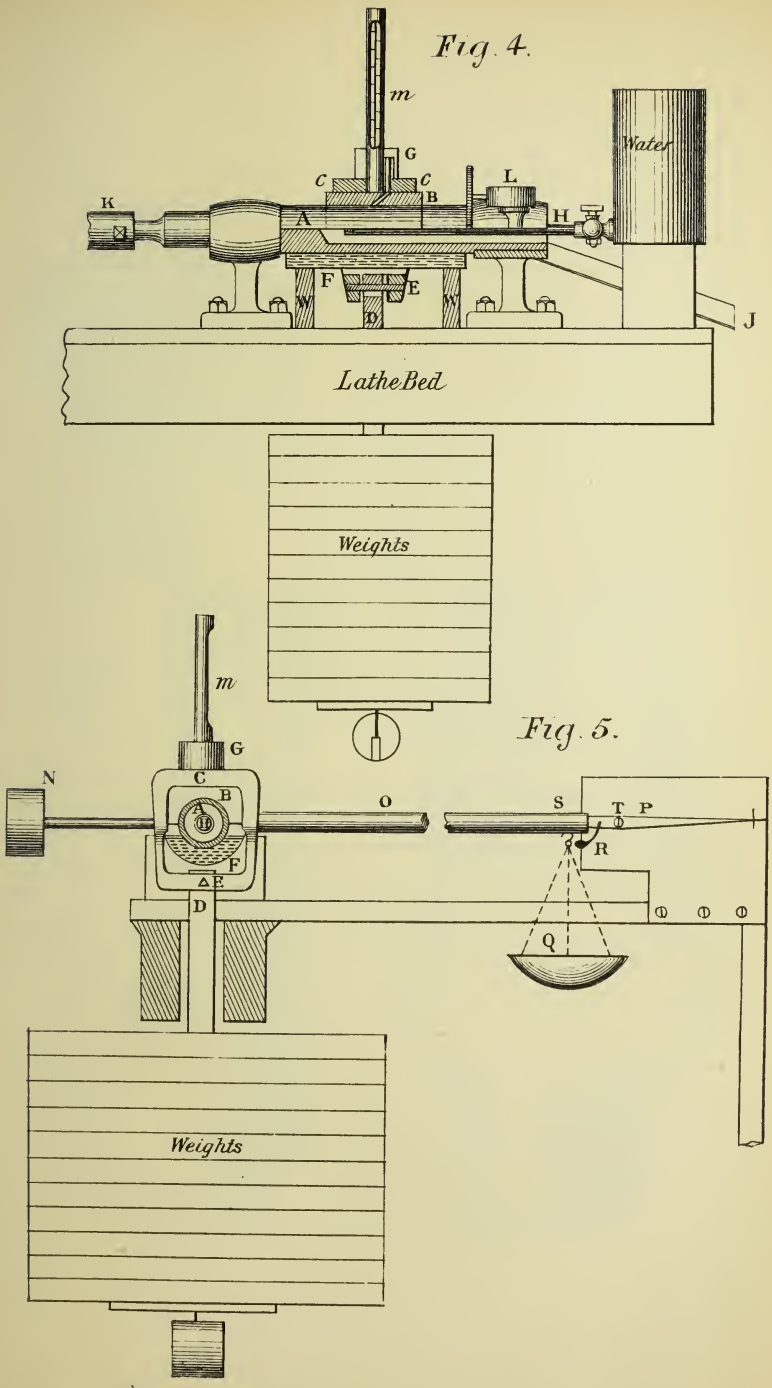
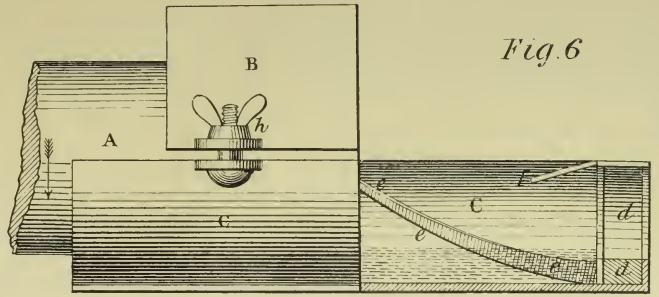
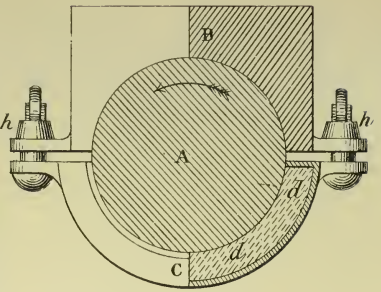


Fig. 4.
m
G
C
C
L
K
B
A
H
Water
F
E
W
W
D
J
Lathe Bed
Weights
m
Fig. 5.
G
N
C
B
A
O
S
T
P
R
F
E
D
Q
Weights

Fig. 6





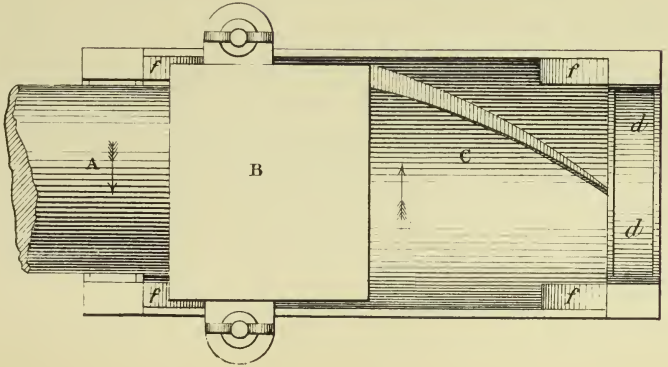


Fig. 6.

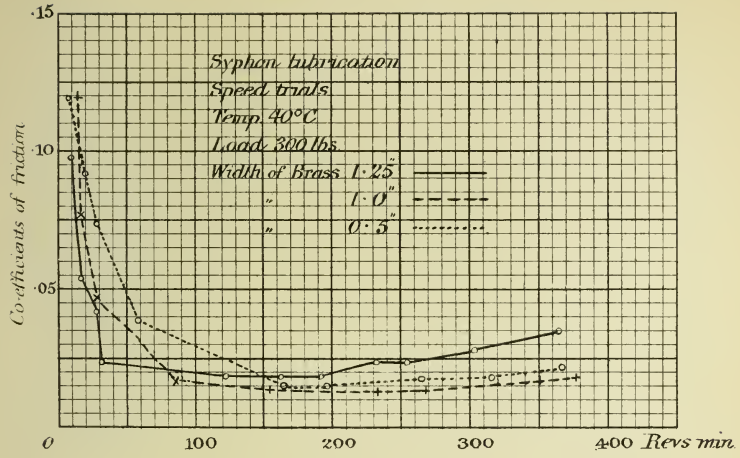

·15
·10
·05
0
100
200
300
400 Revs min
Co-efficients of friction
Syphon lubrication
Speed trials
Temp. 40°C
Load 300 lbs.
Width of Brass 1·25"
" 1·0"
" 0·5"

Fig. 7.

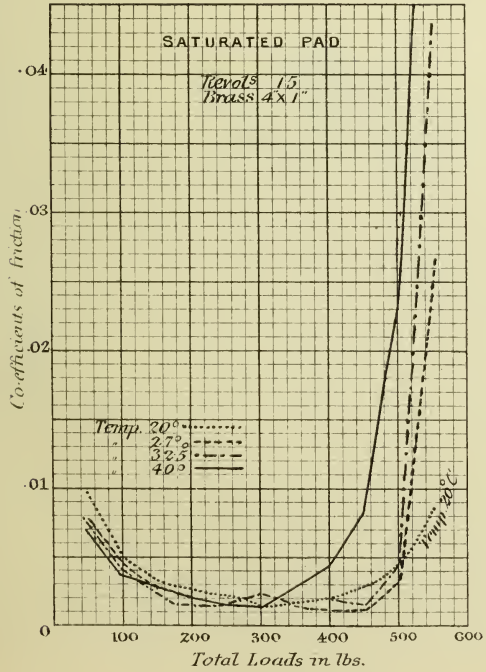

SATURATED PAD.
Revols 15
Brass 4 x 1"
·04
·03
·02
·01
0
100
200
300
400
500
600
Total Loads in lbs.
Co-efficients of friction
Temp. 20°
" 27°
" 32·5
" 40°
Temp. 20°C

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Fig. 8.

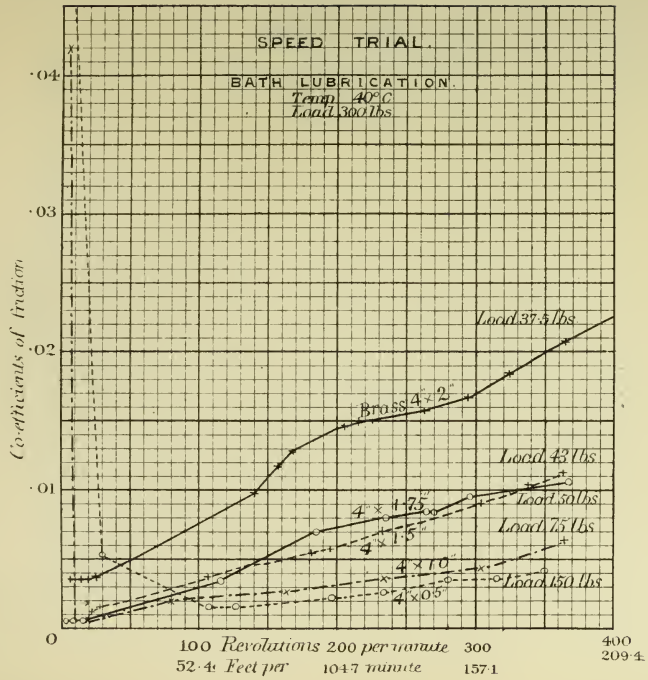
SPEED TRIAL.
BATH LUBRICATION.
Temp 40°C.
Load 300 lbs.
Co-efficients of friction.
·04
·03
·02
·01
0
Load 37·5 lbs
Brass 4" × 2"
Load 43 lbs
Load 50 lbs
4" × 1·75"
Load 75 lbs
4" × 1·5"
4" × 1·0"
Load 150 lbs
4" × 0·5"
100 Revolutions 200 per minute 300 400
52·4 Feet per 1047 minute 1571 209·4

Fig 9

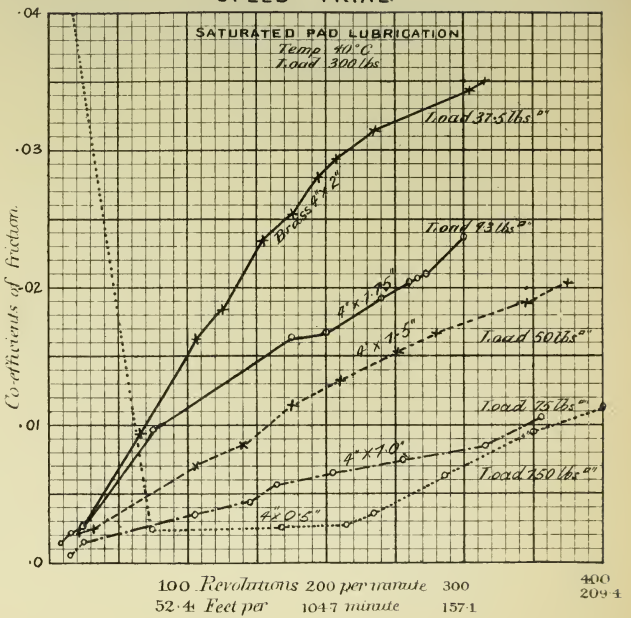
SPEED TRIAL.
SATURATED PAD LUBRICATION
Temp 40°C
Load 300 lbs
Co-efficients of friction.
·04
·03
·02
·01
·0
Load 37·5 lbs
Brass 4" × 2"
Load 43 lbs
4" × 1·75"
4" × 1·5"
Load 50 lbs
Load 75 lbs
4" × 1·0"
Load 150 lbs
4" × 0·5"
100 Revolutions 200 per minute 300 400
52·4 Feet per 1047 minute 1571 209·4

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Fig 10

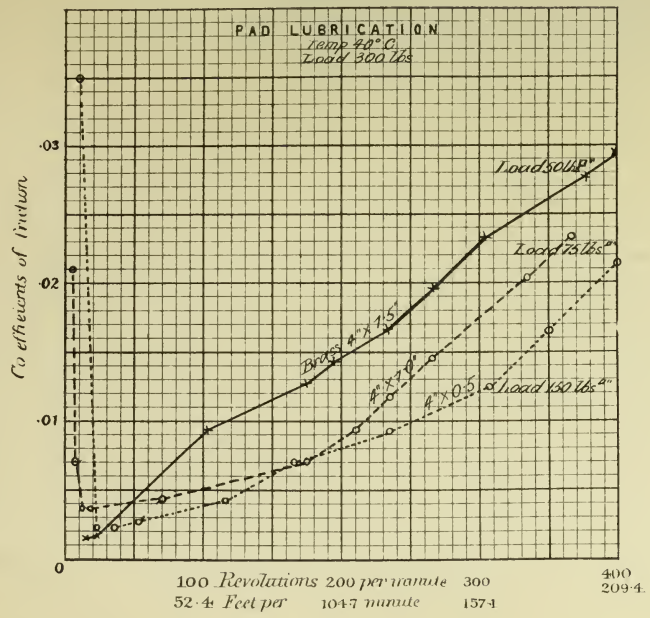
SPEED TRIAL.
PAD LUBRICATION
Temp 40° C.
Load 300 lbs
Co efficients of friction
·03
·02
·01
0
Load 30 lbs
Load 75 lbs
Load 150 lbs
Bridge 4"×1·5"
4"×1·0"
4"×0·5"
100 Revolutions 200 per minute 300 400
52·4 Feet per 1047 minute 1571 2094

Fig 11

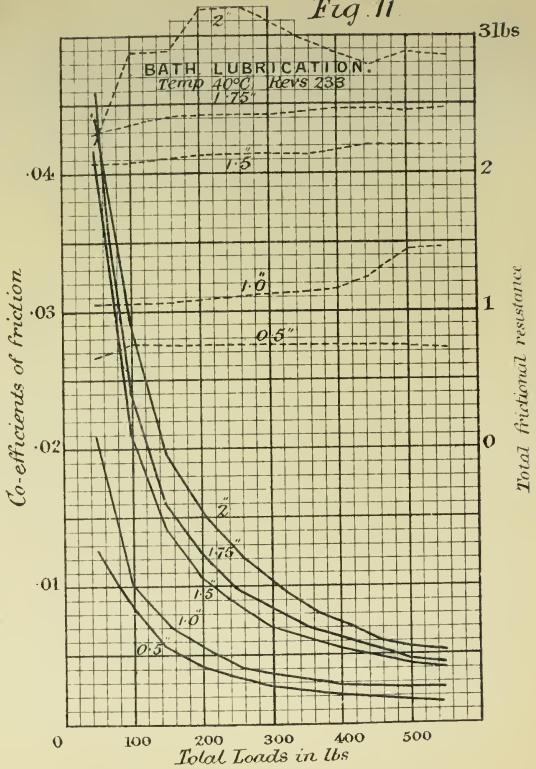
BATH LUBRICATION.
Temp 40°C Revs 238
Co-efficients of friction
Total Frictional resistance (dotted lines)
·04
·03
·02
·01
0
1
2
3lbs
2"
1·75"
1·5"
1·0"
0·5"
0 100 200 300 400 500
Total Loads in lbs

Fig. 12.

SATURATED PAD.
Temp 40°C. Rev^s 233.

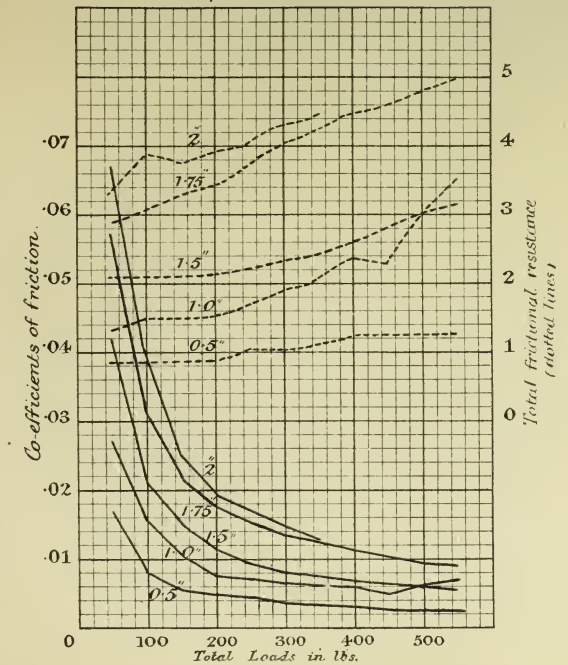

Fig 13.

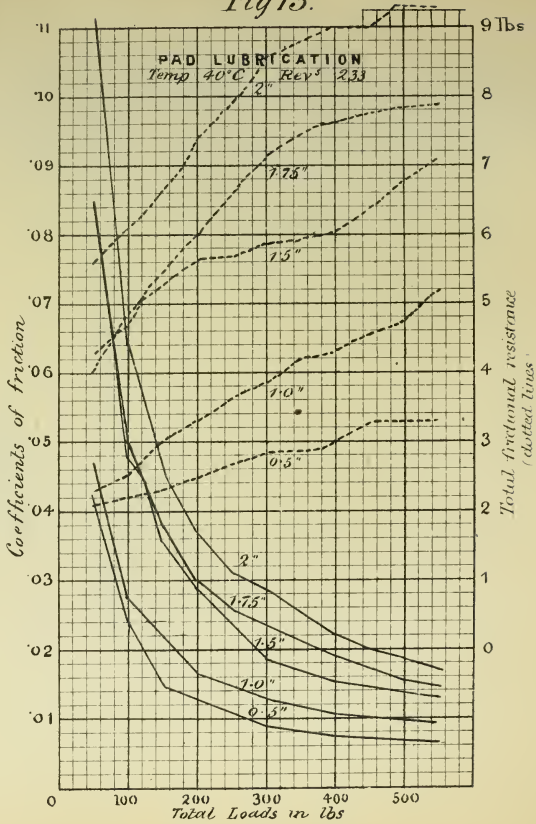

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Fig 14

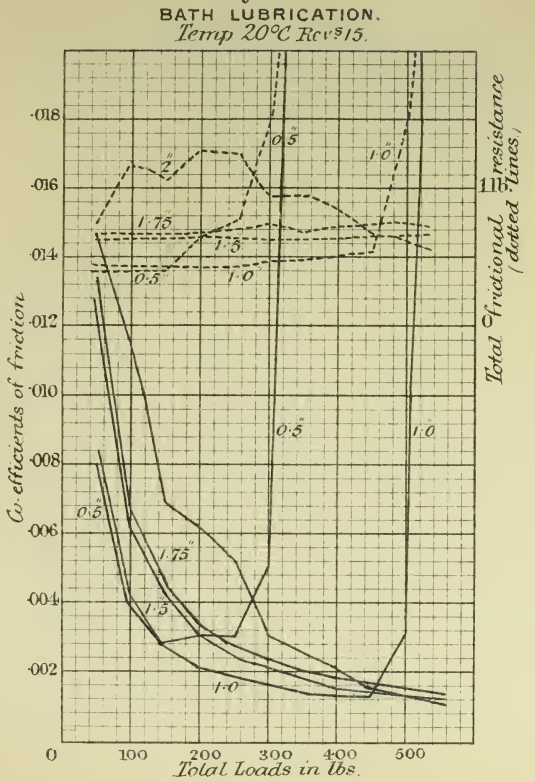
BATH LUBRICATION.
Temp 20°C Revs 15.
Co-efficients of friction
Total Frictional resistance (dotted lines)
Total Loads in lbs.
·018
·016
·014
·012
·010
·008
·006
·004
·002
0
100
200
300
400
500
2"
1·75
1·5
1·0
0·5"
0·5
1·0"
1·0
0·5"
1·0"
0·5"
1·75
1·5
1·0"

Fig 15

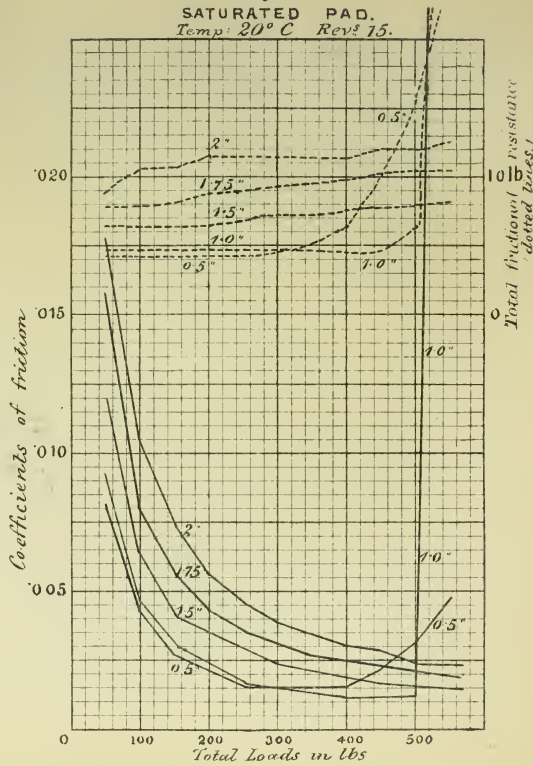
SATURATED PAD.
Temp: 20° C Revs 15.
Coefficients of friction
Total Frictional resistance (dotted lines)
Total Loads in lbs
·020
·015
·010
·005
0
100
200
300
400
500
2"
1·75"
1·5"
1·0"
0·5"
0·5
1·0"
2"
1·75
1·5"
1·0"
0·5"

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Fig. 16

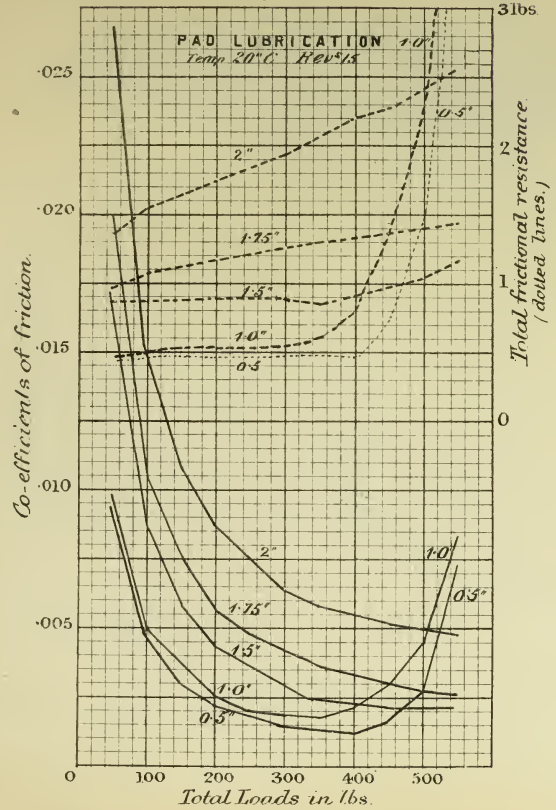


Fig. 16a

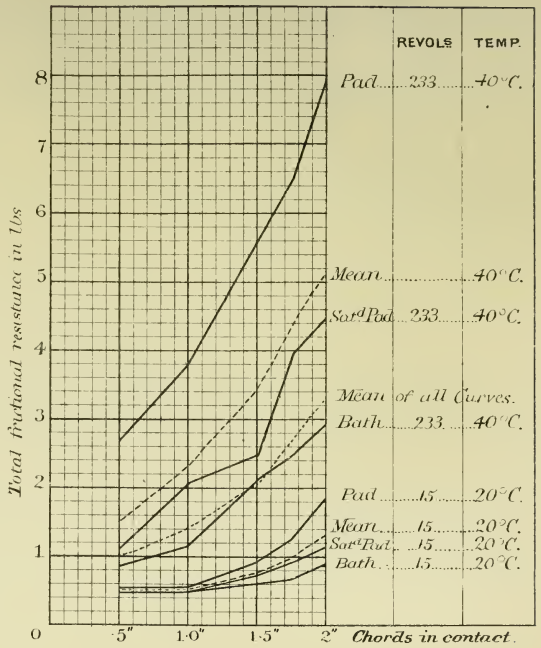
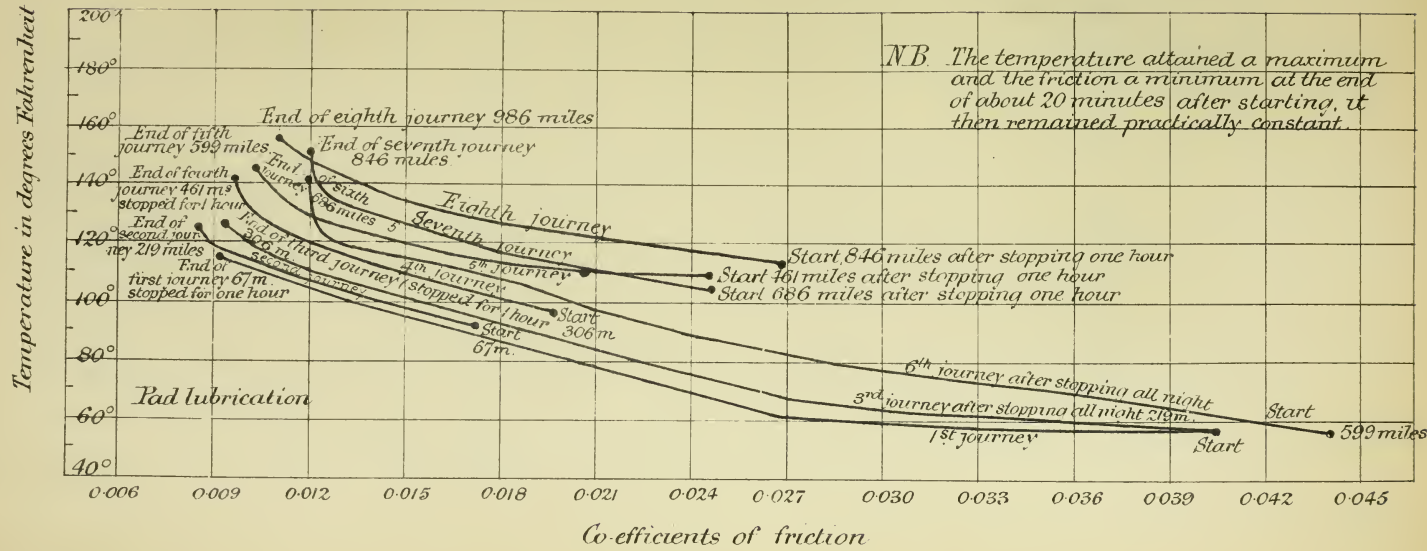


Diagram showing the increase of friction and temperature as the distance increases, with only a limited supply of oil,
Journal 7" diam. Total load on brass 4984 lbs or 237 lbs per sq inch
The miles given refer to train mileage.

Fig 17.

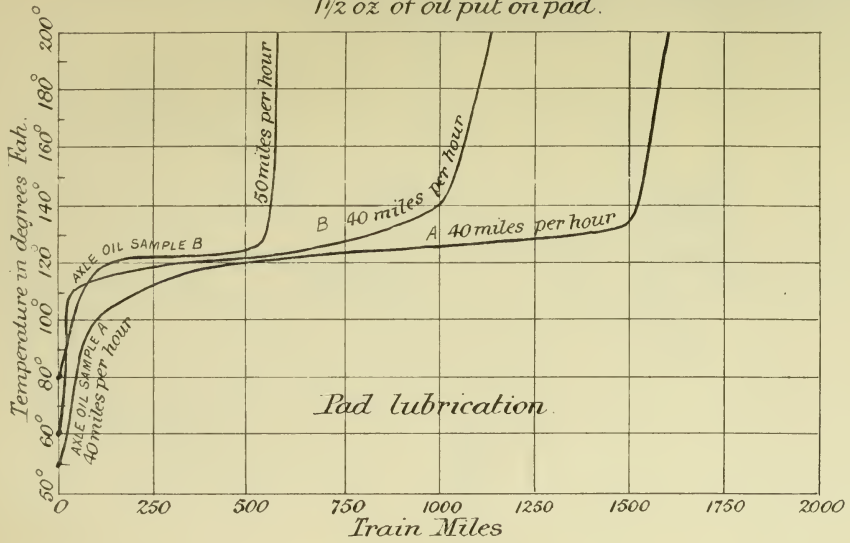
2¼ oz of Rape oil put on Pad. 21 drachms left on Pad at end of run. 15 drachms used in 968 miles.



Manchester Association of Engineers.

Fig. 18.

Diagram showing the durability of lubricating oils.
Journal 3½ inches diameter, load per square inch 333 lbs.
1½ oz of oil put on pad.



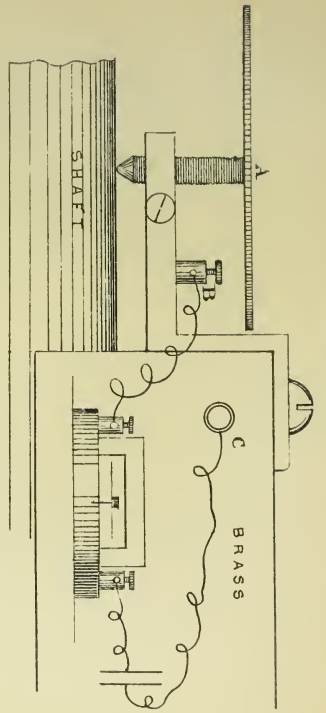


Fig 19.

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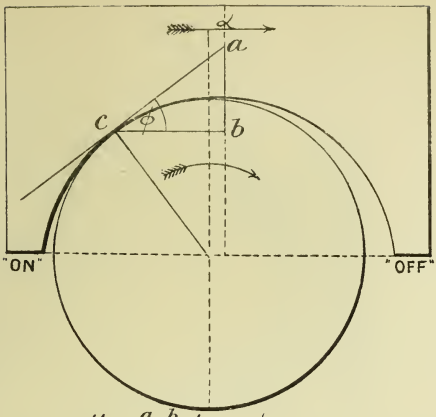
Fig. 20.



$$\mu = \frac{a}{b}\frac{b}{c} = \tan \phi$$

Fig. 21

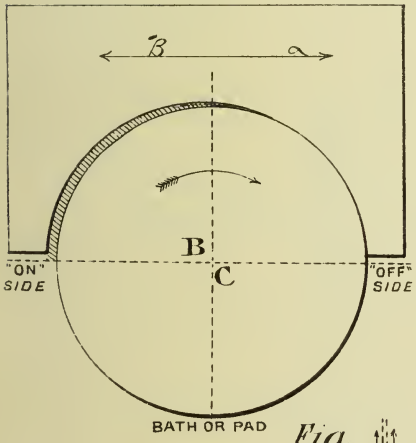


Fig 22

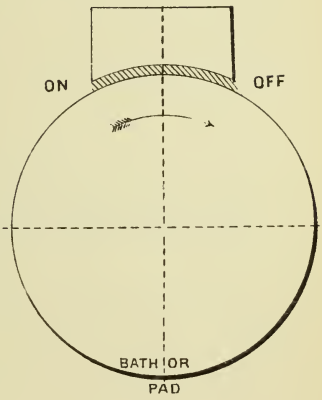


Fig 23.

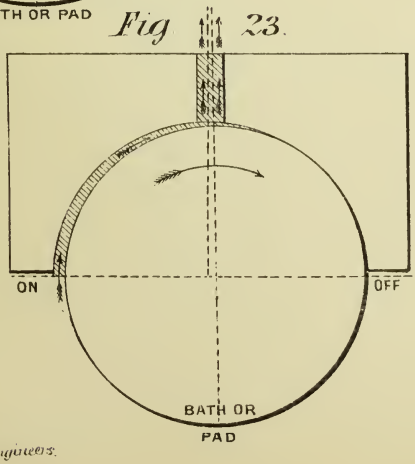


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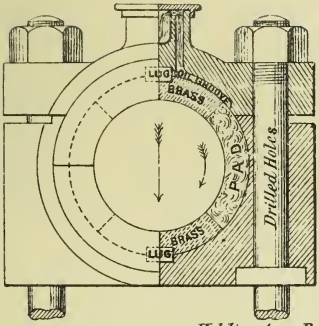
Fig 24.



Holding down Bolts

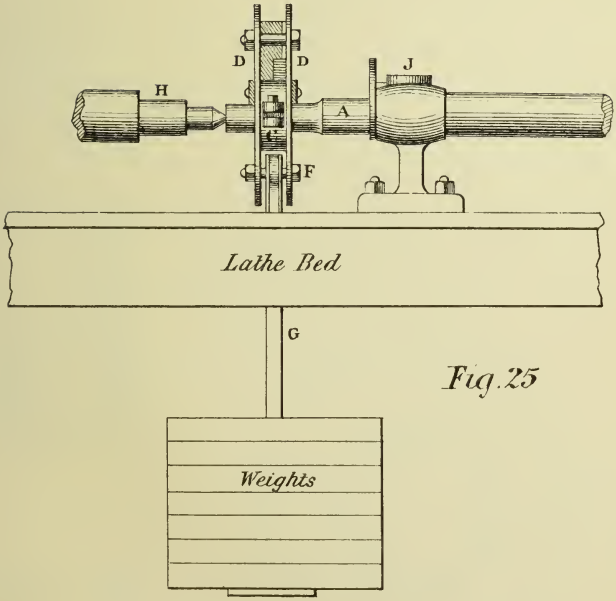


Fig. 25

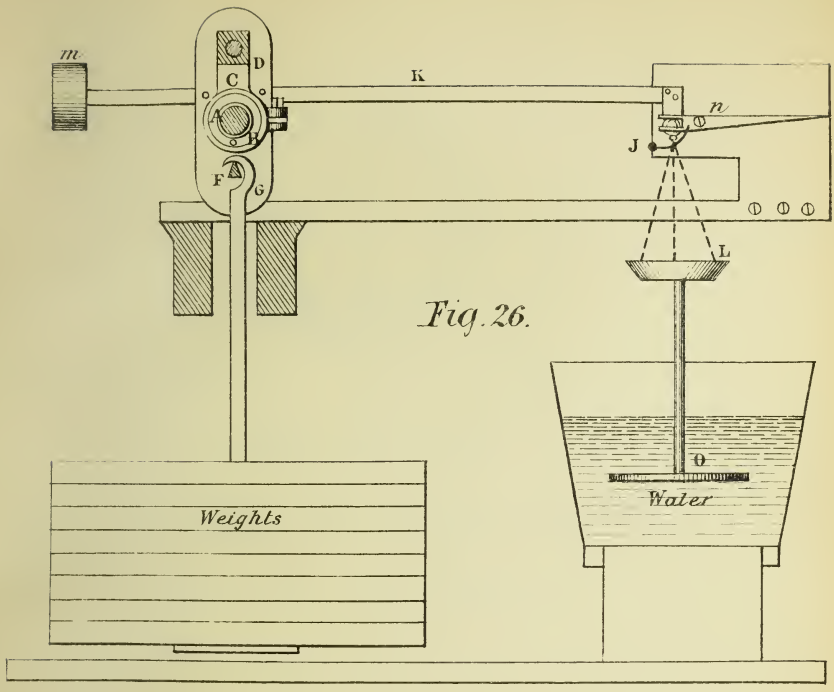


Fig. 26.

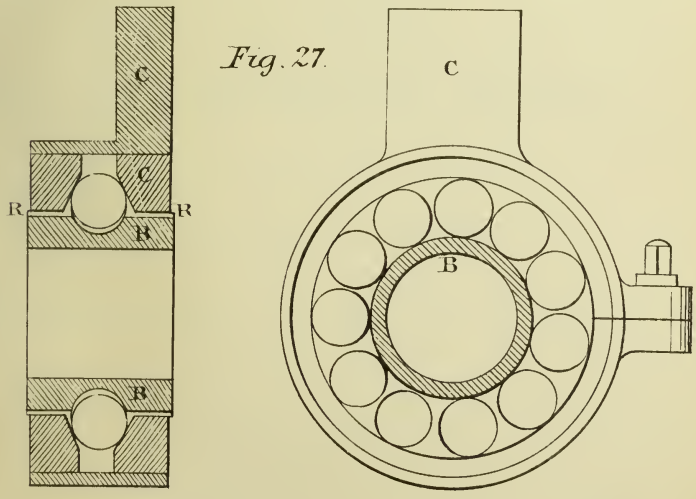


Fig. 27.

FEED WATER,

ITS EFFECTS ON STEAM BOILERS,

AND ITS TREATMENT.

A PAPER

READ BY

MR. E. G. CONSTANTINE, M.I.M.E.,

On 12th APRIL, 1890,

AT THE GRAND HOTEL, MANCHESTER,

MR. JOHN WEST, M.Inst.C.E., President,

IN THE CHAIR.

MANCHESTER:
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1890.

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FEED WATER,
ITS EFFECTS ON STEAM BOILERS,
AND ITS TREATMENT.

The subject I have chosen for my paper is, I need hardly point out, a very important one indeed, and when we consider the number of explosions of steam boilers directly or indirectly resulting from the impurities contained in the feed water, and the destruction to life and property consequent on these explosions (to say nothing of the immense waste of money in other ways from the same cause) we cannot but wonder that this matter does not receive a much greater share of attention.

The ignorance and carelessness concerning the proper working of steam boilers which prevail among a large class of boiler owners and attendants is really astonishing.

I find from the Abstract of Board of Trade Reports on Steam Boilers Explosions during the year ending June 30th, 1888, that no less than 18 per cent of these explosions were directly due to internal corrosion and overheating through deposit This is a state of things not at all creditable, and the sooner it is remedied the better.

A great deal has been written on this subject, containing very much valuable information, but outside engineering circles I am afraid that with a few exceptions, the parties most interested are—or at all events appear to be—supremely indifferent to what might be the means of saving them pounds upon pounds per boiler per annum in cost of fuel and repairs, and, what is of much greater importance, often the lives and limbs of their employés and of persons who may have the misfortune to reside or happen to be in the vicinity of their death-dealing boilers.

It is not so much my intention this evening to give you an original paper as to present, in a compact form, information gathered from a variety of sources, with such remarks as my own experience of the working of boilers may suggest.

I do not purpose introducing marine boilers, as they are worked under somewhat different conditions to those prevailing in the management of land boilers, and there is quite enough to be said about them to monopolize a paper to themselves.

FEED WATER: ITS SOURCES AND CONSTITUENTS.

The feed water supplies for our boilers are drawn chiefly from springs and wells; rivers, brooks and canals; ponds and lakes; mines, rain water tanks, and town supplies—the latter being recruited from springs or surface waters—and these all contain chemical impurities in the form of gases, or solid matters in solution and suspension.

Spring and Well Water varies according to the nature of the earth through which it has passed, and the length of time it has had to act on the substances with which it has come in contact. In passing through the upper layers of the earth rich in mould, it absorbs carbonic acid, and has a further supply of the same gas forced into it by the heavy pressures existing in the bowels of the earth. This carbonic acid enables the water to dissolve and absorb certain quantities of the substances through which it may pass, as calcium, in the form of chalk, dolomite, marl and gypsum; rock salt, barium, iron, manganese, and others. Water which rises in chalk, dolomite, or marl, contains a large quantity of solid matter; but that which passes through gypsum or rock-salt has the most. The average quantity of solid matter in spring water varies from 14·02 to 140·22 grains per gallon, and the minimum and maximum quantities are given respectively as 1·402 and 280·45 grains per gallon. Calcium or lime, in the form of carbonate or sulphate, comprises the chief constituent. This also occurs as chloride, nitrate, or nitrite. Next to this comes magnesium, as a carbonate or sulphate, and oxide of iron, alumina, chloride of sodium and silica are rarely absent, also organic matter and ammonia are frequently present. The gaseous constituents are oxygen, nitrogen and carbonic acid, and sulphuretted hydrogen is also occasionally found.

River and Brook Water.—The composition of river water depends greatly on the source, the distance from that source, the nature of the streams and of the substances brought

into it from inhabited districts, mills and factories, and on the quality of the land drained into it. The further the water is from its source the less carbonic acid it contains, and as an excess of this acid is required to dissolve and hold in solution the carbonates of the alkaline earths, these to some extent are precipitated; on the other hand, the organic and other matters held in suspension are increased, and there is often a large quantity of mud (principally clay and fine sand), especially after rainy weather.

Canal Water.—Very much of the same constituents as river water, with the addition of impurities from works on the banks, and the acids in canal waters are often the cause of serious corrosion.

Ponds, Lakes, and Town Supplies hold larger or smaller quantities of solid matter according to the composition of their feeders, except in the case of town supplies, which are often filtered and thus cleared of mechanical impurities held in suspension.

Mines.—The water taken from iron and coal mines often contains acids which are very injurious to boilers, and I remember examining a boiler fed from pit water which had corroded the plates nearly through in six weeks.

Rain Water is the purest of natural waters, but it always contains small quantities of gaseous and solid matters in solution. Oxygen, nitrogen, and carbonic acid are always present. In one gallon of rain water an average of about 7 cubic inches of gas is found containing from 20 to 30 per cent oxygen, 60 to 70 per cent nitrogen, and 5 to 10 per cent carbonic acid. The solid matter is composed of chlorides and sulphates of calcium and soda, and organic substances; these average ·0492 to ·3498 grains per gallon.

It may not be out of place here to give a few analyses of waters which have been, or are being actually used in steam boilers:—

No. 1.

	Grains per Gallon.	Source.
Carbonate of Lime	2·43	Well, Kingston-on-Thames.
Carbonate of Magnesium	2·67	
Sulphate of Lime	26·38	
Silica	1·39	
Oxide of Iron and Alumina	1·11	
Chloride of Sodium	8·54	
Total	42·52	

	Grains per Gallon.	Source.
No. 2.		
Carbonate of Lime	22·5	Well, Manchester.
Sulphate of Lime	5·0	
Sulphate of Magnesium	14·9	
Chlorides, Nitrates, &c.	4·1	
Total	46·5	
No. 3.		
Carbonate of Lime	32·55	Boring, Pendlebury.
Sulphate of Lime	7·63	
Sulphate of Magnesium	20·79	
Chloride of Sodium	4·95	
Silica	3·40	
Oxide of Iron and Alumina	2·25	
Sulphate of Sodium and Potassium	11·43	
Total	83·00	
No. 4.		
Carbonate of Lime	15·56	Boring, Hull.
Carbonate of Magnesium	8·92	
Sulphate of Magnesium	21·69	
Silica	4·89	
Iron and Alumina	3·19	
Chloride of Sodium	119·19	
Total	173·44	
No. 5.		
Carbonate of Lime	6·71	River Etherow, Broadbottom, near Manchester.
Sulphate of Lime	2·75	
Sulphate of Magnesium	·99	
Chloride of Magnesium	·87	
Chloride of Sodium	1.81	
Oxide of Iron and Alumina	1·74	
Silica and matters soluble in acids	10·34	
Total	25·21	
No. 6.		
Carbonate of Lime	11·80	Canal (supposed) Birmingham.
Sulphate of Lime	53·55	
Chloride of Lime	20·62	
Chloride of Magnesium	6·41	
Chloride of Sodium	61·05	
Total	153·43	
No. 7.		
Sulphate of Lime	6·07	Source unknown, Sheffield.
Sulphate of Magnesium	3·72	
Chloride of Sodium	2·47	
Oxide of Iron	·41	
Silica	·55	
Total	13·22	

	Grains per Gallon.	Source.
	No. 8.	
Carbonate of Lime	·84	Pond, Oldham.
Sulphate of Lime	10·20	
Sulphate of Magnesium	3·00	
Chloride of Sodium	3·20	
Oxide of Iron and Alumina	·13	
Silica	·64	
Total	18·01	

These analyses give a fair idea of the matters met with in feed water, and I will now endeavour to explain the effect on steam boilers, which may be classed under the two broad heads of Incrustation (including deposit), and Corrosion.

EFFECT ON STEAM BOILERS.

Incrustation.—It has been generally supposed that the sulphates of calcium were the only substances which formed real scale, and that the carbonates of lime and magnesia were deposited in the form of mud or slime, and became scale only by the assistance of the sulphate of calcium, or by becoming baked on the plates. Schwackhöfer tells us, however, that many waters deposit adherent and crystalline scale composed almost entirely of carbonates of calcium, and to prove this he quotes the following experiment:—

"If water containing a considerable quantity of such carbonates is boiled for some time in a glass vessel, besides the powdery or flaky precipitates, weak incrustations will be formed, which attach themselves firmly to the sides of the vessel."

This view is supported by my own experience of incrustation, a few samples of which I have been able to obtain for your inspection.

Carbonate of Lime, which is one of the salts met with in the largest quantities in fresh water, is held in solution by an excess of carbonic acid. On the temperature being raised some of this acid is driven off as carbonic acid gas, and the carbonates becoming insoluble are precipitated. As the temperature is increased the precipitation is accelerated, until at boiling point comparatively little carbonate of lime is left in solution. As the lime is precipitated some of it falls in fine particles on the heating surfaces; but by far the greater portion is carried

away by the currents induced by circulation, until it reaches the part of the boiler where this is least active, and there settles. In Lancashire and Cornish boilers this is usually in the bottom of the shell, from whence it may be partially removed by blowing out

Sulphate of Lime is precipitated much more gradually than carbonate, as the elevation of temperature has less effect on it; but, as the tendency to form scale is the greater the slower the salts are laid down, this is one of, if not the chief, scale-forming salt, making the hard, flinty incrustation which is so difficult to remove by mechanical means. It also has the property of binding together carbonates of lime, and silicates in one tenacious, compact crust.

Magnesium is not precipitated in any quantity till the water evaporates; it also acts partly as a cement to the powdery deposit already laid down.

Chloride of Sodium, or Common Salt, is one of the most soluble constituents met with in water, and is only left in a solid state by evaporation. If the water is allowed to become saturated with it, very serious results ensue.

The other substances, such as silicates, oxides, nitrates, &c., are only found usually in smaller quantities, and do not form incrustation except when cemented together by the sulphate of lime and magnesia.

Incrustation and deposit are responsible for a great many evils in boilers, among which may be mentioned the following:—

Overheating, caused by the deposition of scale and mud, or slime on the surfaces subject to the fierce heat from the fire, and by particles of solid matter held in suspension, which to some extent thicken the water, and thus retard circulation. This latter is especially the case when grease or fatty substances are introduced, as these agglomerate with the carbonate of lime in process of precipitation, and by still further thickening the water and adhering to the heating surfaces prevent the proper transmission of heat from the fire, with the effect of overheating the tubes and plates, causing tube ends and furnace seams to leak, fractures from rivet holes, grooving of end plates, angle irons, and at seams, by excessive expansion and contraction; and distortion, bulging and collapse of furnace

tubes and crowns by rendering the plates unfit to withstand the pressure.

A good fusible plug has often been the means of attracting attention to grease in the boiler by partially fusing with plenty of water over the crowns ; this has been in many cases attributed to the fusible metal being too sensitive, but intelligent examination will generally prove the fault to be, not in the plug but in the water.

Loss of Fuel.—This is a point on which there is a great difference of opinion.

Professor J. G. Rodgers is credited with estimating the loss as follows:—15 per cent. when the scale is $\frac{1}{16}$in. thick, 30 per cent. when $\frac{1}{8}$in. thick, 60 per cent. when $\frac{1}{4}$in. thick, and 150 per cent. when $\frac{1}{2}$in. thick. Another estimate places it at 13 per cent. for scale $\frac{1}{16}$in. thick, 38 per cent when $\frac{1}{4}$in. thick, and 60 per cent. when $\frac{1}{2}$in. thick.

On the other hand experiments carried out by the Society for the Inspection of Steam Boilers, in Munich (an account of which is published in the *Mechanical World*, for November 30th, 1883) give such extraordinary results, that I must be pardoned if I give a rather full extract.

These were comparative tests made with purified water and a clean boiler, and with ordinary feed-water saturated with gypsum (a common form of sulphate of lime); the test was continued during 195 hours, day and night, and eight measurements of the water evaporated were taken in order to ascertain the change caused by the increasing thickness of incrustation. It was found that although the thickness of scale averaged $\frac{1}{4}$in. and approached in many places $\frac{3}{8}$in. thick, no decrease in the evaporating power (pounds of water per pound of coal) could be ascertained, notwithstanding the most careful measurements, so that the incrustation showed no influence whatever. It is stated the experiments had unfortunately to be concluded sooner than was intended, because the furnace plates appeared to show signs of becoming hot.

I have unfortunately been unable to obtain particulars of any reliable experiments on boilers, under ordinary working conditions, that would throw light on this subject, but I think the

most reasonable view is, that scale and solid matters in the feed-water in the boiler do undoubtedly cause a considerable loss of fuel, for the following reason, viz.—Heat being motion, anything which disturbs the continuity of the molecular chain along which the motion is conveyed, must affect the transmission; this condition of disturbance is fulfilled by scale, particularly that composed of carbonate of lime, or magnesia and silicates, which if examined through a powerful magnifying glass will be found to consist of very fine particles with minute spaces between them, which spaces tend to interrupt the molecular chain. The scale of sulphate of lime or magnesia is close and more compact, and would not disturb the continuity to the same extent. Floury deposit however, would be worse than scale of either sulphates or carbonates. Loss of fuel may also be due to the presence of solid matters held in suspension, which by interfering with the globules of water rolling over each other retard circulation, and this would be aggravated by the presence of grease or fatty substances, as explained under the head of overheating.

It was estimated by a select committee, in 1882, that in the United Kingdom there were no less than 140,000 steam boilers, exclusive of locomotive, steamship, domestic and greenhouse boilers, and this number must now be greatly exceeded, thanks to the activity of the Lancashire boiler makers. If we assume the percentage of loss to be very small for each boiler, it would amount to an enormous sum in the aggregate.

I should be very glad if the members present would state their experience respecting this important point, which is one that offers a fine field for research to those in a position to make experiments.

Leakage of Shell Seams, caused by unequal expansion and contraction of the plates when incrusted. When this occurs, where the boiler rests on the seatings, which are sometimes from 9in. to 15in. broad, and of ordinary brickwork, a new and very dangerous element is introduced, viz., external corrosion, which may go on undetected until the plates are so reduced that they become too weak to withstand the pressure, and then ——— ! ! !

Furring-up of Feed Pipe, with the attendant risk of the feed supply being restricted or almost stopped.

Wear and Tear, and Repairs.—It follows as a matter of course that where the strains in a boiler are increased by the presence of incrustation, the wear and tear is greatly increased and the life of the boiler shortened, and frequent repairs necessitated. I have known the boilermakers of not very large works kept constantly repairing the boilers through nothing else than the feed water containing a large quantity of carbonate of lime, and by heating the water with exhaust steam from the engines in contact.

Difficulty of Examination.—When the interior of a boiler is covered with thick scale or deposit, the difficulty of properly ascertaining the condition of the plates, and the danger of serious defects being undetected, are very great; for it by no means follows that where the plates are coated with scale there is no corrosion, as this often exists in a bad form, and although this is sometimes apparent by the bleeding which takes place, I have no doubt there are gentlemen here to-night who can bear out my assertion, that it is often impossible to make a reliable inspection when the plates are much incrusted.

It has been asserted that one of the dangers of incrustation is that it may crack off the heating surfaces in large patches, and thus, by allowing water to suddenly come in contact with the hot plates, steam may be generated so quickly that explosion may occur. This theory however is not sustained by experiments, for it has been conclusively proved that when water is admitted suddenly on to red-hot plates steam is not made so rapidly as to constitute this a danger.

If there is much carbonate of lime in suspension the fine particles get into the fittings and damage them, and it may also cause priming ; and serious breakdowns in the engines, by passing with the steam from the boilers.

Advantage of Incrustation.—After blaming incrustation as I have done for causing so many evils, it is pleasant to have something to say in its favour. A very thin coating of scale on the plates is decidedly advantageous in protecting them from the action of some corrosive agents which may be present in otherwise comparatively pure water.

We come now to a worse enemy than incrustation, because it is one which does its work insidiously, but none the less surely, and is often very active entirely unknown to the parties most concerned. I refer to

Corrosion.—Corrosion follows no rule, but is very capricious in the manner in which it attacks boilers. It is generally existent in the form of wasting over small or large areas, pitting or honeycombing, and grooving, and is due to the chemical action of the acids introduced with the water, or formed by the decomposition of the salts and organic substances by the high temperatures in the boiler.

Hydrochloric acid, formed by the decomposition of the chlorides (that of magnesium being especially unstable) is a very active corrosive agent, and one of those most commonly met with.

Acids formed by the decomposition of the chlorides of magnesium and carbonate of lime, of the salts of barium and lime, of the salts of sodium and lime; free oxygen, and the free acid from decomposed grease or fatty substances, are active corrosives.

The acids from the decomposition of iron salts and others are also injurious to a greater or less extent.

Corrosion is also said to be caused by galvanic action in some form, but I have not met with any instances in my own experience to prove this theory.

Wasting is often found at the water level, affecting shell and end-plates, rivet heads, gusset and other stays, or it may extend from about the water level well down the sides of the shell and end-plates, and also affect the lower sides of the flue tubes; it may only be at one end or side of the boiler and not on the other; sometimes it is well defined, the plates being quite rough, and sometimes it is uniform and has the smooth appearance of the perfect plate, and when in this form very careful examination is necessary; a close scrutiny of the seams will generally expose this kind of corrosion, but it is difficult at times to estimate the depth, and the safest plan is to drill the affected part and gauge the thickness of the plate.

Pitting, or Honeycombing, is corrosion in the form of cavities in the metal. These cavities may be as small as

⅛in. diameter, or in patches 10in. or 12in. diameter, and of various depths. Where the pits are very small, and isolated by solid portions of the plate, they may be of considerable depth without materially reducing the strength, but the reverse is the case when the pits are connected by honeycombing, which practically reduces the strength of the plate in proportion to the depth of the pits and the area covered,

Pitting is frequently found on the tube crowns, bowling hoops, end plates, and about the blow-out opening and other parts of the shell.

As previously stated, corrosion sometimes exists beneath a coating of incrustation.

Grooving is, as a rule, not caused by corrosion alone, but is materially assisted by it. Where the molecules of iron are in a constant state of alternate tension and compression, or fretting, they become disunited; the acids attack and oxidise these molecules, and gaps are left in the metal. Grooving, in which corrosion has had a part, is easily distinguishable from that caused by mechanical action only, for in the first case the recesses are much wider than in the latter, in which the grooving may be as fine as the edge of a knife blade.

Many very peculiar instances of the eccentricities of corrosion could be cited, but the specimens before you will give a fairly good idea of this foe to boilers.

TREATMENT.

The best means of preventing incrustation and corrosion is to use suitable water—that is to say, water which contains neither acids, fats, nor organic matter, little of the solids of calcium, magnesium, or sodium, and no nitrates, nitrides, ammonia, or sulphides.

Where such water is not obtainable, the best course is undoubtedly (where practicable) to treat the water before it enters the boiler; and there is a host of patented and unpatented appliances and processes for doing this, which are mostly alike in the respect that each particular one is declared to be better than any of the others in the market.

One of the oldest and best known processes is that of Dr. Clarke, which consists of the addition of lime water in suitable

tanks, which, by combining with the carbonic acid, causes the precipitation of the carbonate of lime, which can then be cleaned out of the bottom of the tanks; and this answers very well where only carbonate of lime is concerned, but as it does not affect the sulphate only half the work is performed when this is present. some other of the processes for softening water more or less improvements on the Clarke system, and in which suitable re-agents are used to precipitate both carbonate and sulphate of lime, give very good results. Feed-water heaters are used with good effect on waters in which the solids can be precipitated by elevation of temperature, the exhaust steam should, however not be in contact with the water. Where the water contains only organic and mineral matters in suspension, filtration will remove these ; but this does not affect the acids it may contain. As a rule, however, the plant necessary for treating the water before it enters the boiler is open to the objections of being somewhat expensive in first cost, maintenance, and attention, and of occupying a considerable amount of space; and the practice most generally prevailing is to treat the water *after* it enters the boiler, either by mechanical means, or by the use of some substance or re-agent which shall perform the work chemically.

It is a striking proof of the seriousness of the evil that so many remedies have been, and are being, tried ; and were I to give a list of one-tenth of these remedies (real and supposed), my paper would be prolonged beyond all reasonable limits. It is sufficient to say that some of them are eminently successful, while others (and these the majority) are utter frauds. If steam users would exercise a little more common sense on this point, and ascertain what the feed water contains, they could then discover what they really had to contend with.

Different classes of water require different treatment, but for water containing the impurities most ordinarily met with the use of soda in various forms has given extremely good results; and in this connection I cannot do better than repeat some extracts from "*The Practical Engineer's Pocket-book and Diary for 1890*," as this information is based on many years' practical experience of the subject, both from the engineer's and the chemist's point of view :—

Carbonate Waters.—"Where carbonate of lime alone is present: For *each* grain of carbonate of lime found in the water by analysis, 1½oz. of pure caustic soda per 1,000 gallons of water used will be required to effect the precipitation of the lime."

Sulphate Waters.—"Where there is only the sulphate of lime present, for every grain of sulphate found in the water by analysis 1¾oz of pure carbonate of soda (soda ash) are required per 1,000 gallons of water used."

Carbonate and Sulphate Waters.—"Where carbonate of lime and sulphate of lime are both present, as is often found to be the case, the use of caustic soda will be sufficient to precipitate both salts in the following proportions:—

"A water containing 6 grains of carbonate of lime per gallon would require (see above) $6 \times 1\frac{1}{2}$oz. = 9oz. of pure caustic soda per 1,000 gallons of water, and this quantity of caustic soda would suffice for eliminating also 8·16 grains of sulphate of lime, so that a water containing 14·16 grains of solid matter per gallon, of which 6 grains were carbonate and 8·16 grains sulphate of lime, could be treated by simply adding a sufficient quantity of caustic soda to remove the carbonate of lime.

"Take an example:—A Lancashire boiler evaporates, say, 4,000 gallons of water per day, which on analysis is found to contain 26·32 grains of solid matter per gallon. Of this 6 grains are the carbonate of lime and 16·32 grains the sulphate of lime, the remaining 4 grains consisting of silica, iron, &c. What quantity of soda should be introduced daily?"

"By the above rule 6 grains of carbonate requires $1\frac{1}{2}$oz. $\times$ 6 — 9oz. of caustic soda per 1,000 gallons $= 9 \times 4 = 36$oz. per day. This will also precipitate 8·16 grains of sulphate, $16{\cdot}32 - 8{\cdot}16 = 8{\cdot}16$ grains of sulphate left to be treated, Then as 8·16 requires $1\frac{3}{4}$oz. of carbonate of soda per 1,000 gallons, we have $1\frac{3}{4} \times 4 = 7$oz. of carbonate of soda required."

It is very important that the soda should be of the best quality, as trouble is frequently experienced with the boiler and fittings if it is impure or adulterated. It should be dissolved in water and injected into the boiler with the feed water or by a small special pump.

Now although soda will precipitate the lime and magnesium salts, and neutralise the effect of acids on the plates, it does not destroy the salts but simply makes them insoluble, and if these are present in any great quantity in the boiler they constitute an evil by depositing on the plates, not as scale but as mud and accumulating there; consequently it is much the best plan to partially treat the water before it enters the boiler, and this can be done in a very simple and effective manner by having a tank with a partition in the centre, and a plug or drain cock in the bottom of each division. The tank should be made sufficiently large to hold several hours supply of water; into one division the water is pumped from the well, and the soda or other suitable re-agent is introduced into this compartment, and by mixing with the water precipitates part of the solids, the water runs over the division plate (which is left a few inches from the top) into the other compartment, where the precipitation process is still further carried on; the feed supply is taken from near the top of this compartment. If the water can be heated by means of the exhaust steam (not in contact) the process is greatly facilitated, and it will be found that a very large portion of the solid matter is left behind in the tank, which can be cleansed periodically through the plugs in the bottom. The soda still left in solution enters the boiler with the feed and completes the process there, with the result of having much less mineral matter in the boiler,—and what there is left can be got rid of to some extent by judicious blowing out.

Proper re-agents not only purify the water but act on the scale which may have formed on the plates, by gradually softening and making it porous, and by getting between it and the plates loosen it so that it comes off in patches. Steam users often however run away with the idea that this should be performed in five minutes (more or less), and if this is the case they are greatly disappointed, for they should bear in mind that the scale has probably taken a long time to form, and also the fact that if a composition should be introduced sufficiently powerful to dissolve or disintegrate incrustation quickly it would probably contain acids which would also remove more of the surfaces of the plates than they bargained for.

Mr. Lavington E. Fletcher, in his monthly report for May and June, 1869 (in which he gives some valuable information and instances of the evils of floury deposit and grease in boilers), lays special emphasis on the importance of having a scum or surface blow-off arrangement to get rid of the fine particles of carbonates of lime and magnesium which rise to the surface of the water, and there is no doubt that by the frequent and methodical use of such an arrangement a great deal of the impurities can be disposed of and without much loss of fuel. Blowing-off should be regularly resorted to, to get clear of the solids in the bottom of the boiler. If this is done for a few seconds when all is quiescent, such as first thing in the morning and during meal times, much good is done at little cost.

Where chloride of sodium or common salt is present in any quantity, the best method is to keep the water below a certain density by scumming or blowing out. Soda or other re-agents have little or no effect on it as it is so very soluble, and a considerable waste of fuel is caused by the frequent blowing-out necessary to keep down the density, which should be frequently tested by a salinometer.

Boilers should never be emptied with steam up. When about to shut down the best plan is to draw the fires, allow the steam to get down to about 10lb. or 15lb., blow out a few inches of water, and allow the boilers to stand until the brickwork in the flues and fire bridges is cooled down, and then run the water out. If this is done the deposit is mostly soft, and can be washed and brushed out. A great deal of incrustation is formed by blowing out when all the brickwork and plates are hot, and thus baking on the surfaces what ought to be washed out as sludge or mud.

It has been asserted that galvanic action, induced by the contact of zinc with the iron of the boiler, is the best and only trustworthy remedy for corrosion, and that so long as the metallic contact is maintained, little or no corrosion will go on. This has, I believe, been successfully tried in America, but in my opinion it is more suitable for marine than land boilers.

A few simple tests for impurities in water may be of interest :—

1. Test for Carbonate of Lime or Chalk : Add from five to

ten drops of oxalate of ammonia in a small test tube. If carbonate of lime be present, the water will show after a little while a clouded or milky appearance, and in a few hours a precipitate will be found at the bottom of the tube.

2. For Sulphate of Lime or Sulphuric Acid: Add a few drops of nitrate of baryta or barium chloride. If present it is indicated by a milky appearance, and by the formation of a white precipitate.

3. For Decomposed Animal Matter: Add one drop of permanganate of potash, which communicates a bright violet-rose colour to the water when first added. If decomposed organic matter be present the colour is changed to a dull yellow; if present in larger quantities the colour will in time disappear.

4. For Iron: If, upon adding a few drops of solution of prussiate of potash, a blue colour is produced directly or after some time, it shows that iron is held in solution.

Special Recommendations to Steam Users.—I would specially recommend to steam users the great importance of having a quantitative analysis made of their feed water, which can be done at a small cost, and which will enable them to ascertain whether it is suitable for the purpose.

Beware of boiler compositions which are advertised as "cure-alls," for it is impossible to supply a composition suitable in quantity and quality for any kind of water unless the nature and quantities of the impurities in that water are known.

Get your boilers inspected by efficient men, for, although your engineer may be an exceptionally clever man, unless he has had a very wide experience in matters appertaining to boilers, he may over-estimate some trivial defect or underestimate some grave danger, which would at once be pointed out by a person who had made this subject a special study.

Conclusion.—It is now my pleasant duty to acknowledge that I have derived much information from the book on "*Fuel and Water*," by Schwackhöfer and Browne; the "*Treatise on Steam Boilers*," by Mr. Robert Wilson; "*The Locomotive*;" and the paper on "*Boiler Incrustation and Corrosion*," by Mr. F. J. Rowan. And I am also greatly indebted to Mr. Lavington E. Fletcher, Mr. Henry Hiller, and Mr. Michael

Longridge, for according me the privilege of inspecting records and for the loan of specimens.

The Litholine Company, who have had such extensive experience in the scientific treatment of feed-water at home and abroad, kindly furnished me with the analyses given and the samples of incrustation.

In order to keep this paper within moderate limits I have been obliged to omit much that, in my opinion, would have been useful, and if the members desire any further information I will endeavour to satisfy them.

DISCUSSION.

Mr. J. Horsley asked if the results of chemical action were the same on steel as on iron.

Mr. T. Settle enquired if the furring-up of feed pipes with deposit occurred where the pipes were made of copper instead of cast iron; also, whether there was any appreciable advantage in extending the feed pipes half the length of the boiler instead of only about six or seven feet.

Mr. John Taylor stated that he had never found any effective results to accrue from the use of boiler compositions, or any remedy for corrosion. At the same time he might mention that he had found caustic soda and soda ash had the most appreciable effect in loosening the scale from the boiler, though he used it in much greater quantities than was recommended by the author. Occasionally when boilers had been stopped for cleaning, he had made a liberal decoction of the soda and injected it into the boiler, when the pressure had been reduced to about 12lbs; the boiler was then allowed to stand a couple of days, and that had the effect of loosening the scale and facilitating its removal by the men. In his opinion it was nearly impossible for a boiler to be cleaned without eventually using tools and manual labour, and he instanced a case of a

boiler at one time under his supervision, in which was found a layer of deposit 3in. thick; this had to be broken up in order that it might be passed through the mud-hole. Afterwards, in carefully examining the inside of the boiler, he perceived the hammer marks on the rivet heads, thus showing that the water although so full of deposit, had had no injurious effect on the iron. It would be beneficial to steam users, in his opinion, if certain waters were analysed and a general antidote against incrustation and corrosion prepared. He thought that the author might have advantageously alluded to the adoption of economisers and their effects on different waters.

In conclusion, Mr. Taylor said that he did not think any danger would result from using the waters usually procurable in Manchester.

Mr. Terry observed that the subject of the purification of feed water had been treated by Mr. Driffield, and that gentleman advocated similar methods to those mentioned by the author. He might say that it was perfectly useless using boiler compositions without first analysing the water. He had analysed a considerable number of boiler compositions and had found the basis of the majority of them was soda ash, each containing as much water as possible, some as large an amount as 64 per cent. He should like the author to state if he had had any experience in cleaning tubular boilers.

Mr. James Hartley, replying to Mr. Taylor, maintained that there were remedies for corrosion, and that if such were not the case, boiler owners in Manchester would soon have the fact impressed upon them, as the town's water was of a very corrosive nature; further, if a boiler were worked up to its ordinary capacity without soda or other preparation being used to negative the bad action of the water, that it would be very soon worn out.

As an instance of boilers being cleaned by manual labour, he said he was acquainted with a firm who had 23 boilers, one of which was thoroughly cleaned every week by a set of men specially chosen for that purpose. The result of so effectively clearing the scale from the boilers was that there was a weekly

saving in the coal consumption of one hundred tons, although the same amount of steam was being used as was required before such a systematic cleansing of the boilers was in force.

Alluding to the waters in towns, he said there was a great deal of difference in their constituent parts. In Manchester for instance, it was very corrosive when working at a certain temperature. With Dublin and Cork water there was little, if any, corrosion when the boilers worked constantly, but when they were worked only intermittently, they corroded quickly. It was very desirable, nay, absolutely necessary that owners of boilers should be thoroughly conversant with such details if boilers were to be used to the best advantage. In a boiler he recently examined in Cork, which had only been working about four months, he found as much as $\frac{1}{32}$in. deep pitting in the plates. It was very advisable when boilers were not working, that they should be kept quite dry.

Respecting marine boilers, which were now being freely used on land as well as sea, he might say that in that type of steam generator there was not the same facility for blowing off the sediment as in the Lancashire type; in other words, they were not provided with a thoroughly good blow out tap. Wherever there was floury deposit there should be a frequent and regular use of the blow out tap, either before starting in the morning or during meal times. Regarding the furring up of feed pipes with floury deposit, he might say that recently while examining a boiler he noticed certain fluctuations in the feed delivery; it was apparent that the fluctuation was not due to the economiser pipe; the feed pipes were ultimately disconnected and found all right, but on taking off the suction pipe it was found that the inside diameter was actually reduced to a $\frac{3}{8}$in. hole, and which of course had caused the fluctuations.

With reference to the theory of the scale cracking off and causing the pressure to rise, he thought if the safety valve as recommended by boiler inspecting companies were used, there was very little to fear from any accumulation of pressure which might occur.

With respect to using exhaust steam he might remark that it was a common practice to use it in contact with the feed water,

but in such cases he recommended that it should be employed on the surface condensing principle.

In his opinion, the practice of putting large quantities of soda into boilers was injurious in every way.

He advised all boiler owners to fight shy of boiler compositions, and only to treat the water with antidotes after it had been subjected to analysis. The addition of a scum apparatus to a boiler was very advantageous, but of course it should be applied when the water was level with the scum troughs, and not 5 or 6 inches above them. With reference to boilers being blown off under steam, he might add that it was a very injurious practice, as in such cases the fact of the flue being hot, actually baked the scale upon the plates.

In every works there ought to be spare boilers, as in his opinion the additional outlay would be amply repaid, and further that boilers should be thoroughly inspected by a man specially trained for the work.

Mr. A. Rea observed that he had listened to the paper with the greatest possible pleasure, and he thought it would be readily admitted that no better remedy against corrosion and incrustation could be suggested than that of seeing that each kind of water was analysed before attempting to treat it with any specific antidote. There was no doubt that incrustation did of necessity absorb a considerable quantity of heat, and in support of this assertion, he might mention a case with which he was connected where an 11in. exhaust pipe between the cylinder and condenser was actually reduced to a 1in. hole, simply by successive layers of carbonate of lime, &c.; and in that instance, the coal consumption per horse power per hour averaged the enormous quantity of 17lbs.

Respecting corrosion, he did not think that this should be altogether attributed to the water, as he was of opinion that in many cases it might be traced to the impurities in the iron or steel. He knew of a boiler which was composed of charcoal iron, and although it had been working for the last 20 years with canal water, at the present time there was no evidence of pitting or corrosion; on the contrary, there was a boiler working under precisely similar conditions to the foregoing, which

although it had only been made and worked during the past six years, had grooves in $\frac{3}{8}$in. deep. At the present time there was a great demand for steel boilers, but he maintained that boilers made of charcoal iron were much better and certainly more effective in resisting corrosion.

Mr. W. J. Jenkins remarked that some time ago his firm had considerable trouble from several vertical boilers they were working. London water was being used, and the boilers were continually leaking round the furnaces. This was at first put down to bad workmanship, but on examination this opinion was only partly confirmed. On examining other boilers about the works, the same complaint was made even about the Lancashire Boilers used for supplying steam for boiling and heating purposes. In one particularly bad instance, where the boiler was about 8ft. diameter, made by a well known south of England firm, the leakage had been so bad that new furnace tubes and angle irons had been supplied, although the boiler was quite new. No sooner, however, had the new furnaces been put in, than the boiler was again leaking between the angle-iron ring and the furnace tube. A dispute arose about payment, and the boiler was on the point of being condemned, but prior to legal proceedings being taken, it was mutually agreed to submit a sample of the water to an eminent chemist for analysis. The chemist eventually recommended that the water should be boiled in open tanks before being sent into the boilers. Tanks were therefore supplied, and the water boiled as directed, and then the leakage entirely ceased.

The foregoing incident, he thought, bore out the author's remarks about the deposit on the furnace crowns causing unequal expansion. He might further mention that at the present time he had a boiler which was supplied with water from the Rochdale Canal, and knowing the acid, dirty state of that water he was astonished to find that year after year the inspectors reported it to be in as good condition as when originally inspected. At one time he treated the water with pure caustic soda, but that had an injurious effect on the brass fittings, and at the present time he was using a composition,

recommended by a local firm, which was very effective, the deposit being friable and easily swept out.

The Chairman characterised the paper as one of great interest, and said that it would be a valuable addition to the transactions of the Association. The subject, he said, was one in which all engineers were more or less concerned, and it certainly was surprising that more practical science had not been brought on the treatment of water, to avoid the extraordinary revelations which were made anent the formation of scale.

On the motion of the Chairman a cordial vote of thanks was passed, by acclamation, to the author for his able and instructive paper.

Mr. Constantine thanked the members for the attention which had been accorded to his paper, and proceeded to refer to the remarks made thereon. With reference to the effects of waters on iron and steel, he believed that there were great differences ; there was no doubt that impurities in the iron were more easily affected by corrosive agents in the boiler, than where the latter was made of pure charcoal iron. He had not had any particular experience regarding the furring up of copper feed pipes, but judging from the copper coils used in breweries, they would, like the latter, become more or less coated with deposit. He believed in the feed pipe being extended to a considerable length in the boiler, provided it was freely perforated, as if the water was ejected from the end, it fell in one solid mass, causing a considerable lowering in the temperature, and consequently absorbing more fuel.

Replying to Mr. Taylor, he maintained that the quantities of specifics named in the paper were sufficient to cause a reaction, if the water contained such solids. As a matter of fact, the quantities depended simply upon the amount of mineral deposits in the particular water to be treated ; but to eject soda in the large quantities suggested was certainly injurious in every way.

The Manchester town's water was certainly very good as far

as deposit was concerned, but he concurred with Mr. Hartley, that unless a little soda was used, it was very corrosive.

Mr. Jenkins had spoken very favourably of the Rochdale Canal water, but he himself had had so many unpleasant experiences with canal waters, that he would hardly venture to use any with a boiler, without it being first subjected to analysis.

Replying to Mr. Terry's question, he was unaware of any method of cleaning the scale off the tubes of tubular boilers, other than drawing the tubes.

He was very pleased to hear Mr. Hartley's practical remarks, but the instance he had given of cleaning boilers by manual labour was exceptional, since under such circumstances it depended on the constituents of the scale. There is the further danger of the tools cutting into the plates and leaving a recess for any corrosive action to attack.

Mr. Hartley's reference to the necessity of an efficient blow out tap was very appropriate, since if it was necessary to have such a fitting on a boiler at all, it certainly should be as effective as possible.

GRAPHIC TABULATION AND SOME RELATIONS OF ART TO ENGINEERING.

A PAPER

READ BY

MR. H. GUTHRIE, C.E.,

On 25th OCTOBER, 1890.

AT THE GRAND HOTEL, MANCHESTER,

MR. JOHN WEST, M.Inst.C.E., President,

IN THE CHAIR.

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GRAPHIC TABULATION AND SOME RELATIONS OF ART TO ENGINEERING.

Mr. President and Gentlemen,

I was tempted to offer this paper to your Council on the strength of the success of several previous efforts on similar lines, but in slightly different spheres, and I certainly think the subject deserving of more attention than it generally obtains. Every day shows more and more how Art and Science depend upon each other for mutual support and development. My first serious attempt in this strain was with the architects of Liverpool when I tried to show how much they depended upon science and rule and figures for their vaunted, so called, inspirations in beauty. Now I take the opposite side of the question, and purpose trying my hand at showing how we engineers can make use of the beautiful in our everyday life and practice. Not only on the inducement of its beauty and the pleasure we may experience in its contemplation, but because of the regularity and the mathematical properties of which beauty essentially consists.

Mind you, I am not going to credit our English system of weights and measures with any part in adding to the beauties or conveniences of mankind, for a more unsystematic, irregular and inharmonious compilation could scarcely exist. Nor can I even compliment our forefathers in choosing ten figures instead of eight, which would undoubtedly have been the best basis of nomenclature.

The beauty of my subject however does not depend upon anything human, but upon the principles of nature itself.

I need not therefore trouble you with reciting the history of the art of numeration, and so follow in the footsteps of my brother, the Accountant, who read a paper a short time ago under that title, and exhibited many calculating apparatus and machines which would have been exceedingly interesting to this Association, and which our council will do well to remember as a subject for the future.

Our subject appeals direct to a faculty of mankind, and which engineers especially should and, I should hope, do possess in a higher degree than the average of mankind. I refer to intuition or the power of recognising the difference, instantaneously, of regularity of form or place. Beginning with the most simple of all cases: we all of us like to see symmetry in our structures, in which we recognise the rudimentary arithmetical figure 2, and though we do not think of the figure 2 everytime we recognise symmetry, still it is the essential element which satisfies and gives the idea of balance and harmony. This figure 2 pervades all engineering works as well as all art works. In the same way we intuitively recognise the triplet, the quartet, and many following increasing numbers in arithmetical progression. And the more the eye is trained the greater is the number which can be intuitively recognised.

These however, are only the simple addition relationships, and do not tax the brain of the ordinary engineer in the least.

The next higher stage is that of compound addition relationships or simple multiplication. For instance, we may place many forms of symmetrically arranged dots on a board, look at them for a period of a flash of lightning only, and we shall be able to tell the numbers ; whereas if those dots were irregularly placed it would require a laborious and individual count to ascertain with accuracy and certainty the exact number. I do not know that anything can be more convincing of this than the fact that our whole telegraphic system depends upon it. Thus by the very simple combination of two sounds with two periods of time, we talk from city to city with lightning speed. For with comparatively little practice the mind soon recognises the meaning of the two sharp ticks of a receiver needle caused by its striking the low toned stop, followed by one tick at a longer period of time upon the high toned stop, and as quickly recognises the difference of meaning if the same time is kept but with the tones reversed, or with the same tones and the time reversed.

I have often wondered why clock makers do not take a hint from this and arrange the striking by periods. Thus, if one does happen to be in doubt whether it is 11 or 12 which is

striking, he has to carefully count each stroke, which, in the case of our own Town Hall clock, or indeed any other large timepiece, is a necessarily slow process; whereas if the strokes were made in rapidly delivered groups we should know without counting, and with even more certainty what those strokes meant. Who could mistake that .... meant 12; and even if our mind were busy with other thoughts at the moment of hearing those sounds, the impression is distinct and can be recalled and recognised as 12 at pleasure long afterwards.

Likewise, should the last of the three groups of four be short of one stroke, thus .... how easily the difference is recognised without counting, whereas it would be quite impossible with our present system of barbarous monotony. The clock makers do follow the more enlightened process in the chimes, having two bells; but I am sorry to have to think that this good feature did not spring so much from their intelligence in recognising the intuitive qualities of the brain, as from their fear of that brain muddling up the striking bell with the chiming bell, and so the only alternative was to have a duplex tone for chiming the quarters and a monotone for striking the hours. If there are any clock makers present perhaps they will enlighten us as to whether they decline to improve from lack of enterprise, or are prevented from improving by public prejudice; for that it is for want of intelligence I cannot believe.

Proceeding further, vast quantities can be intuitively recognised if they are presented to the mind, either graphically or by sound in some systematic and harmonious way. By the bye, that word harmony is one of the most abused words in the English language. It is often used with an indefinite value in the arts generally except that of music, where it has a very definite value; so definite indeed that it is purely arithmetical in its meaning, and is used in no other sense in that art. Musicians have known for a very long while why notes harmonise with one another, and that to obtain harmony some simple relationship of numbers of vibrations, such as two to one, two to three, or three to four must exist. I do not want to weary you with too much rudimentary or introductory matter, but I know of no better or more interesting way of leading you to the heart of the matter than by presenting to you my old

graphic map of harmonies of form, sound, and colour or light. (See Fig. 1.) This diagram has been constructed to show, in as simple a way as possible, the theory of harmonies. On the left hand side you may observe part of a key board of a piano. It is not drawn to a regular scale from the cabinet maker's point, but it is drawn to a regular scale from a scientific point of view, as you will presently see.

Thus, the perpendicular line along the edge of the keyboard is divided into numbers of vibrations per second, every vibration having an equal space allotted to it; that is to say, it is drawn to a scale, just as you would draw a machine so many feet to the inch, but instead of feet I have put vibrations. Now, if we hit upon any arbitrary note and find out the number of its vibrations and the length of its wave, and draw a line equal to the length of its wave, opposite to the point on our scale, we have a true representation of that note. This is what I have done in the diagram, but instead of taking any note arbitrarily I have taken an accepted list, and shown each note of a little more than two octaves by the black horizontal lines, and connected their ends with a curve. You may imagine those lines represent the wires of a piano. And now, by a very simple process, we can recognise the laws of harmony.

Let us take the lower note of the octave, called "C," indicated by the dark horizontal line with a dot at the end.

1st.—We will divide this line into *two* equal parts, and draw a perpendicular from the point of division. This, as you see, just strikes the upper "C" at its extremity, showing there are *two* vibrations of the one to *one* of the other.

2nd.—Let us divide the line into *three* equal parts, and draw perpendiculars as before. Here we find one exactly striking the end of "G," showing there are *two* vibrations of one to *three* of the other.

3rd.—Let us divide this same line into five equal parts, and here we find a perpendicular drawn from the first division just strikes the end of the line denoting "E," showing that there are just *five* vibrations of the one to *four* of the other.

We have now marked out the four notes of the octave, most simply related arithmetically, and those four notes we find,

make up what is called a "chord" in music, and recognised as the most perfect harmony.

I might carry you further into the analysis of musical relationships, and show how the other divisional points by drawing perpendiculars from them would strike notes in harmony octaves above, but enough has been said to show the nature of the diagram, and how it demonstrates the theory of harmony in music.

If we take the art of colouring we may deal with it in an exactly similar manner. And anyone who likes to refer to Mr. Proctor's little science book on "The Spectroscope" will be able to see that by simply reducing the scale 144 times we get the colour diagram line for line on the sound diagram. We thus demonstrate that the art of colour harmonies depends as much on arithmetical relationships as sound and form.

We have parallels of what we may call simultaneous harmonies, that is to say, several notes struck at the same instant, and several colours mixed up together.

And we have parallels of harmonies of association, that is to say, notes in harmony closely following one another, and colours in harmony in close juxtaposition. Such are the simple parallels of relationship. But we may, and commonly do, employ both kinds of harmony in the same composition.

In playing a tune, every time the hand strikes the keyboard it produces harmonies of the first order, and all following strokes produce harmonies of the second order, the tune itself being a combination of the two.

And so with colours, we may have any number of mixed tints, or we may have the elementary colours in harmonious juxtaposition, or we may have mixed colours in harmonious juxtaposition, and we may have as many varieties of colour composition as musical composition.

These parallels of harmony between music and colour may also hold good to a large extent in form, though they are not at first so apparent. This however is our next step, and the one more closely concerning the engineering profession. The typical line being that one on our diagram which joins the ends of the scaled lines representing the length of the waves of vibrations, and is the simple curve of inverse ratios. A formula the

engineer stumbles across more often than any other, namely: twice the distance half the breadth, or half the length twice the breadth.

Diagrams made with these lines (Fig. 3) can be made to serve innumerable purposes for the use of the engineer. In its simplest form it is the multiplication table concentrated to such an extent that the product of any two figures can be read off at sight more or less accurately, according to the scale to which such diagram may be drawn, even to several decimal points. By this means we get the area of any surface, however large. That is to say, if divided by vertical and horizontal lines on the decimal system, for by that system we can alter our scale and readings at will to a tenth, a hundredth, or a thousandth; or *vice versâ*, to ten, a hundred or a thousand times, just as suits our convenience. In fact it is the exact equivalent of the slide rule, but with several advantages over that very useful instrument; for besides being able to square dimensions and find the square root it at once enables you to see the exact proportions. Thus for instance, having obtained the superficial area necessary for your purpose and represented by one of the curved lines, you may move the imaginary corner of your rectangular figure to any point on that line, and know that in altering the proportion you are not altering the essential element, the area. This is often very useful in scheming.

By a very simple addition to this diagram, viz., by repeating itself underneath, we can extend the use of the simple curve of inverse ratios to very wide fields indeed; for, by tracing the curved line representing area down to the base line, and then perpendicularly down to a fresh horizontal representing the third dimension, we obtain the cube quantity required. And here again the diagram is more useful than either the ordinary cube root tables or slide rules, for we do not always want what is generally understood as the cube root, namely: one figure, which if multiplied by itself twice will make the principal; but we often want to know what three odd and widely different figures will give us a certain cubical contents, and I know of no other method which gives you, at once, these figures together with the graphic representation of the exact proportions.

For the purpose of substituting this graphic table for the ordinary squares and cubes and square and cube roots : the diagonal line on the upper portion of the table represents the squares and the figures, directly opposite either along the top or side are consequently the square roots. In the lower portion of the diagram an additional curved line is required (again a beautiful curve, but different variety) thus : to find the cube root of 125, it is only necessary to trace the finger down this extra curved line until you find that value as indicated by the series of curves (see figure), then by tracing the horizontal line to the left we at once find which is the cube root required, or, *vice versâ*, if the cube of 5 is required we at once find it on the cube curved line to be 125.

For myself, I have put these diagrammatic tables to many uses, amongst which is that of quantity taking and estimating, and during my appointment at Gorton Foundry in this capacity, I depended entirely upon this little diagram (Fig. 4) for calculating or rather reading my quantities, whether in brass, copper, or iron, and I found that I could read my quantities as accurately as from a printed figured book, about $1\frac{1}{4}$in. thick, containing 147 pages and 103,194 readings, and this at three or four times the speed.

In fact I found, like many others, that the ordinary ready reckoner was so cumbersome, and took such a time to turn over the leaves and find the figures required, that one could as often as not reckon it out as quickly, if not quicker, on a slip of paper. Moreover a few small sheets like this can be carried about on one's person without inconvenience, whereas to carry the same amount of information in ordinarily figured tables would require an attendant handcart.

I have often thought that it would be a good speculation for some enterprising printer or engraver to publish similar sheets to these, simply ruled and without the index figures, so that each purchaser could put his own index and so adopt a universal diagram suitable to his own peculiar requirements. I had some thoughts of offering to draw a series of such sheets, if your council thought proper to reproduce them for the benefit of the members; but even if this were acceptable I cannot at present afford the time to do them, as I should like at once to make them a credit to

myself as well as to the Association to which I have the honour to belong. Such series would have to be adaptable for either the decimal system, or for feet, inches, eighths and sixteenths; tons, cwts., qrs. and lbs. of wrought iron, cast iron, steel, copper, brass, stone, wood, water, or anything else; or contents in gallons; or using English dimensions to read off metrical quantities; or *vice versâ*, to use metrical dimensions to read off English quantities.*

I know that some may say that diagrammatic tables can only be read approximately, and therefore their use is very limited; but those who have really used them, I think, will agree with me in saying that their approximateness is so near that they serve as well for 90 per cent. of an engineer's calculations of similar formula. For after all, are not even more than 90 per cent. of his calculations only matters of estimate and not absolute? For instance, if we want to know what sized column is required to carry a certain load, is not the load itself in the first place a matter of estimate? Is not the strength of the metal a matter of estimate? Are not the conditions under which it will work a matter of estimate? Then why pretend that a decimal point or two in the answer is of any importance? Neither do we put into the boiler the exactly calculated number of superficial feet of heating surface, but make it a little more or less according to the convenience of getting the tubes into the available spaces. The particular table I have referred to has stood the test of years of actual practice, and hundreds of thousands of pounds in value have depended upon its use.

Diagrammatic tables I admit are not suitable for casting up accounts and balancing books. I am not going to advocate their use to clerks and accountants, unless for the purpose of testing the honesty or personal equation of the individual. For there certainly is room, in reading between the lines, for a little more or less, according to the inclination or bias in the case.

* Members must kindly remember that the figures published with these proceedings are only meant to illustrate the system, and do not pretend to be sufficiently accurate or complete for use.

In the lower part of fig. 4 the ½ and ¼cwt. lines were omitted in the loose sheets given round at the meeting, but are now put in. The odd lbs. are guessed, and guessed quite as accurately as a plate can be rolled; and it should be remembered that plates are more often rolled too thick than too thin, for the simple reason that plates too thick would pass an inspection when those too thin would be condemned.

The engineer however, in his ordinary calculations, has no bias in the matter. He simply wants to know the nearest approximation to the truth, which the diagram is capable of indicating.

An old private note-book of mine which I have here, and to which any of you are welcome to a glance, contains many diagrams for different purposes; all of which are formed of beautiful curves, and partaking more or less of the nature of the curve of inverse ratios already referred to, and some of which I will draw your especial attention to.

In the matter of analysis of formulæ, I know nothing equal to the diagrammatic to show up the influence of each item upon the final result. For by constructing curve upon curve, each additional line, or rather the space between each additional line and the last one, we get a perfect chart of the question. A process both very interesting as well as instructive.

I should much have liked to have made a number of these analytical diagrams of formulæ in daily use, but the time at my disposal has not permitted; nor even if it had permitted my making the diagrams, the time at our disposal here would not have permitted the study necessary to appreciate and discuss them. It is a matter, however, I think might be taken up more in the class room than it is, or rather was, in years gone by. I do not know what may be done now in these more enlightened times.

I would yet refer to another phase of usefulness to which diagrammatic formulæ may be put, viz: to test the accuracy of formulæ whether treated analytically or not.

To illustrate this I cannot do better than refer you to that diagrammatic table in my book, which I have here enlarged and which is reproduced in Fig. 2. It is indicative of the strength of columns. Here then is an example that should break down all sticklers for standard formulæ. It is truly surprising with what a small degree of approximateness we are often satisfied and are prepared to swear by, under the impression that they represent a true and narrow path from which to divert would be fatal. How many such formulæ would prove equally bad, if put to the Art test, I cannot say.

In the instance before us, the faulty item in the formula is that which supposes that the substance or material used has a

definite crushing strength in the same way that it has a definite tensile strength, and yet it is with this erroneous notion that most of our tables on constructive matters have been founded.

It is all very well to say that a material has a definite *tensile* strength of so much per square inch, because the nature of a tensile strain does not materially alter the conditions, however long the bar. But it is a very different matter when we talk about a definite *crushing* strength, for, regardless of length, I challenge anyone to find it.

The crushing strengths shown in tables of general reference are, as you know, the strengths of cubes only. Anything longer than a cube will *not* bear so great a strain, and conversely, anything shorter than a cube *will* stand a greater strain. The former is acknowledged and is the whole purpose of the formula, but strange to say, the latter is not. There is no sharp point, as indicated in this formula, where the metal has received its ultimate load. The ultimate load is infinite. And since the proportion on either side of the cube change very rapidly, it behoves us to remember it. The point in the diagram indicating the cube will probably be the sharpest part of the curve. Here then is a great feature in the art of diagramising formulæ.

On the sheet before you is represented accurately two formulæ. The original diagram represented by the series of lines is formed from the formula indicated arithmetically at the top of the sheet. It is the best I know for the purpose. The one strong black line represents Hodgkinson's formula, so universally used. The Hodgkinson formula, you may observe, is wofully wrong. The other formula is also wrong but to a less extent. The proper formula would be represented by a line similar to the dotted line, which speaks for itself as right in character, and therefore the others are wrong.

If experimenters would use a diagrammatic system of registering their data, they would probably find out the proper character of formulæ easier than without it, and be far less likely to fall into errors of this sort. Take the matter of the strength of columns just referred to. If a series of dots had been made on a sheet of paper ruled for the purpose, and a sweet curve drawn through them, or rather in their general direction, it would have told at once that any terminable formula would be wrong.

Before leaving the subject of curves I would like just to refer to a few objects which most of us admire exceedingly, though a few do not approve of showing publicly; objects which we do not usually associate with dry mathematics, and yet the more mathematically accurate the form the more we admire. I refer to the human female figure which is composed of little else than varieties of peculiar curves of mathematical precision. Indeed the art of the sculptor consists in so posing his figure as to show, from every point of view, the greatest possible variety of these curves. On the diagram there is shown an accurate outline of the lower part of a beautiful lady's face (this has not been reproduced in the illustrations); you will find it purely mathematical, and we may look at a beautiful face from what point we like, we shall find this same kind of curve repeated over and over again. And further, tracing the outline of a good figure downwards we see other varieties of perfectly mathematical form in the neck, shoulders, arms, hips, and last but not least, legs. I do not think it is the morbid inclination to the indecent which makes, not only, most men but most women also, admire a good pair of legs; but it is the beauty of the curves and their mathematical properties which create the charm.

Nor are beautiful curves confined to the human female figure. They pervade all nature. The pigeon and floral illustrations (with the exception of the claws and very small touches) were all drawn with this mathematical curve. Feathers are very mathematical both in outline and detail; but I must restrain enlarging upon this, lest I leave no room for other matter which I wish to notice before closing.

With the curve and rythmic matters which we are able to appreciate intuitively, the art of diagrammatising is by no means exhausted. We often see in books a jumblement of triangles which we are told represent the strains on a structure, but we have to take the author a great deal for granted, since there is no demonstration in the diagram itself as to which line represents the strain on particular members of the structure, except by laboriously referring to reference letters and notes. And it is this which, I think, disgusts many students and, especially so if they are quick at figures, causing them to put down diagrams often as stupid bosh. Take an instance from our

standard pocket-book, "Molesworth's," say the "Strains on Polygonal Framing." (See Fig. 5.)

Here we have to transfer our sight from one figure to another, and carefully to notice which line of the diagram of strains refers to each member in the structure, either by reference to the index figures or by observing which lines are parallel, and in cases where different members of a structure are parallel, this latter mode is impossible.

Why not draw the diagram on the figure itself, as shown in Fig. 6.

Here every information is concentrated *at* the point to which it refers. It speaks for itself. No index letters are necessary. No explanations wanted. And what is more, it proves itself accurate, for if F does not equal G then it is wrong. I have here several constructional diagrams illustrative of my meaning.

Nor is the diagram limited to the calculation of strains, it may be further developed into the proper disposal of the several parts of each member; that is to say the plates, angles, and even the rivets, so that a skilled diagramiser might put nearly every information on one diagram for an intelligent draughtsman to make a complete set of working drawings.

Leaving the subject of diagrams and coming down to ordinary tabulation, there is even some art in putting a mass of irregular figures together. Let us turn to "Molesworth" again and refer to "Dimensions of Locomotives"; say, we wish to refer to the heating surface, we find a lot of figures placed side by side and want to note the difference; but it is not so easy to note a difference in figures so placed as if they were one above the other, the position in which we would naturally place them if we transferred them to a piece of paper in order to work it out. And again it would be a material assistance in this and many such tables if a space were allowed between the 10in. and 12in. cylinder, to show at sight that the sequence of information was wanting, and that therefore we should expect a larger gap at this point in the value of the series than anywhere else. And, talking of gaps, these are often very useful in grouping tables in regular sequence, such as every five or ten lines. Then again we may sometimes substitute for the gaps a different kind of type. And further, when making manuscript tables we have

still more license, for besides using different kinds of figures or different size of figures, we may use differently coloured inks or figures or differently coloured grounds. Here I have a table of logarithms which I have used a great deal in taking out quantities in civil engineering work. I coloured this book determining that the white columns should be the initial or index figures first to be found, and next that all plain tints should indicate superficial area, and that all tints with a darker line down the middle should indicate cubical contents. Thus, one tint suggests one multiplication, and two tints, two multiplications. I then settle that green shall indicate inches; red, feet; yellow, yards; and blue, the weight of wrought iron. These few items are not difficult to remember, so that after a few references I never need glance at the top of the column, or be in the least doubt of choosing the right figure.

Again in my table of weights of tubes I write the figures relating to iron in blue, copper in red, which are both suggestive to the engineer's mind, and brass in black.

But while advocating these aids to quick reference I certainly do not approve of their being entire substitutes for titles. I think every page should have the title of each column at the top, and this for several reasons. First, that an engineer generally uses many tables and cannot remember all the arbitrary regulations he has laid down: but glancing at the top he is reminded, without the trouble of referring to the beginning of the series or to special notes; and, secondly, tables are as often as not required for other people's information besides that of the composer, so that sufficient information should be at hand to inform any ordinarily technical mind, without having to serve an apprenticeship to know what this and what that means. Tables of this sort are hieroglyphics to the uninitiated or casual user, and often only waste the time they were designed to save, and perhaps cause errors into the bargain.

DISCUSSION.

Mr. E. G. Constantine said he should like to know why the author preferred eight figures in the notation table to ten. He fully concurred with the remarks regarding impressions made upon the brain, as there was no doubt that these very often occurred, though not noticed till sometime afterwards. The brain was undoubtedly assisted by the eye, as was evinced by the general fondness for pictures, or of any subject which was graphically delineated. He thought the offer of the author to construct a series of diagrams for the members would be greatly appreciated, since they would be of great value in checking formulæ given in standard works, which he need not say were not always reliable.

Mr. D. Fulton remarked that their thanks were due to the author for introducing a subject little known, and a very beautiful side of science that governed engineering. He must confess however that from the title of the paper he expected more would have been said on the engineers' training from an artistic point of view, which he considered to be equally as necessary as the purely scientific part of his training. In every other profession dealing with structures they found that beauty and utility were combined, but in the majority of cases the productions of the engineer were exactly the reverse, the only desire being that a structure should bear a specified strain or weight. He though it would have been a good thing if the author had endeavoured to impress upon the members of that Association the absolute necessity of uniting with the ordinary engineering training a much larger share of purely artistic training, and in fact the address naturally led up to that point, since the curves to which reference had been made were mathematical curves, and they commmended themselves to the eye by reason of their beauty of outline.

Mr. Joseph Nasmith was of opinion that the art of graphic tabulation could be made to serve a very useful purpose, and that it might be developed in a variety of ways. As an instance of effective graphic delineation, he said he could cite no better case than that which occurred at a recent Fabian lecture. In order to show the amount of wealth produced in this country and the manner in which it was distributed, a large circle was drawn and coloured black. That colour indicated the amount of wealth in the country, and its distribution was shown by white divisions, according to the opinion of the lecturer. The general effect was very striking, and it conveyed to the mind the idea much quicker than if a series of figures had been submitted to the audience. There was no doubt that graphic tabulation, however strange it might appear at first sight, was worthy of great attention. To a person who was studying any abstruse subject, the ability to express it by a plotted diagram on paper was of infinite value, in that it enabled him to exactly ascertain the work of the particular mechanical parts. Again, the applicability of graphic tabulation to the calculation of weights was equally advantageous on account of the saving of time which resulted, and which every one knew was such an important factor at the present day.

Mr. F. Wiswall wished to express his appreciation to the author for the very admirable paper which had been submitted to them. It had been his fortune to be connected with ships and shipbuilding for a many years, and he believed it was necessary that a designer should have a thorough knowledge of curves before he could design a beautiful ship, the curves of which he maintained were in all respects truly mathematical.

Mr. Bentley desired to add his testimony to the value of the paper. He thought, however, that if the author could be induced to extend his studies, and to put the results in a pocket book, similar to that of "Molesworth," it would be a compilation which would be of infinite value to the members, and redound to the credit of that Association.

Mr. Joseph Davis said he had listened with great pleasure to the author's paper, and he could in some slight measure testify to its practicability, as he himself had made use of graphic tabulation in the construction of large structures, such as bridges, etc. The late Professor Maxwell, of Glasgow University, had made some studies on graphic tabulation, but he, Mr. Davies, had learned that the papers had been left in such a form that only fragments had been preserved. He trusted, however, Mr. Guthrie would still pursue his studies in this excellent science, and in due time favour them with the results which he believed would be appreciated by the members of that Association.

Mr. H. Guthrie, in replying, said the reason he advocated the numeral 8 instead of 10 for the basis of our nomenclature was on account of the former figure being capable of being divided by two to unity, so that 4 would equal a half, 2 would equal a quarter, and 1 an eighth; a natural division for most tables of weights and measures.

Graphic tables, in his opinion, would be very useful for checking formulæ given in books, which as many then knew were far from perfect.

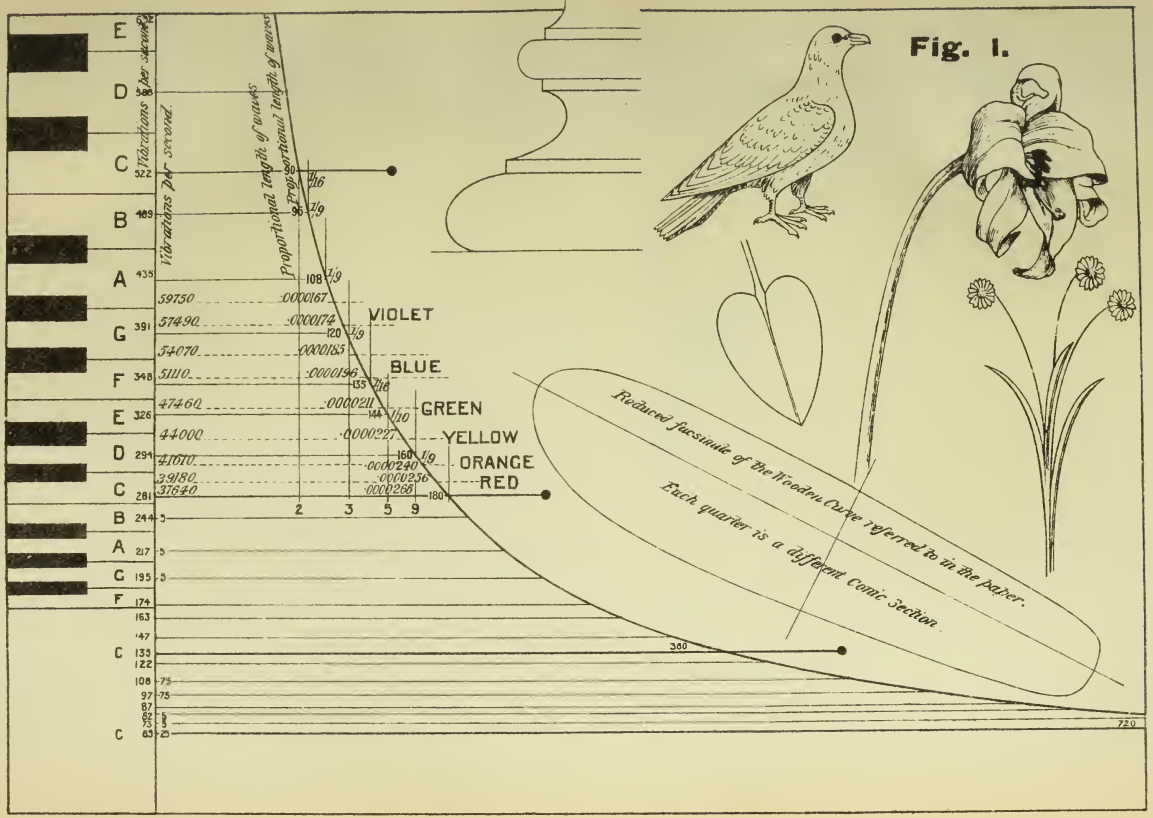
Mr. Fulton had told them that he anticipated more would have been said in the paper in relation to the artistic training of engineers, and in reply to that he could only say that nothing would have given him greater pleasure than to have extended his remarks as indicated, but it would be very apparent that the field in that direction was practically unlimited. He was glad to learn from Mr. Wiswall that the curves of ships were based on scientific lines, since there was no doubt that it was upon their arithmetical or mathematical precision that the speed of ships depended.

He was pleased to learn from Mr. Davis that such a high authority as the late Prof. Maxwell had intended to construct a series of diagrams on similar lines to those which he (Mr. Guthrie) advocated.

On the motion of the President, seconded by Mr. Jos. Nasmith, a vote of thanks was accorded to Mr. Guthrie for his paper, which he briefly acknowledged.

DIAGRAMS.

To illustrate Mr. H. GUTHRIE'S Paper on "Graphic Tabulation."



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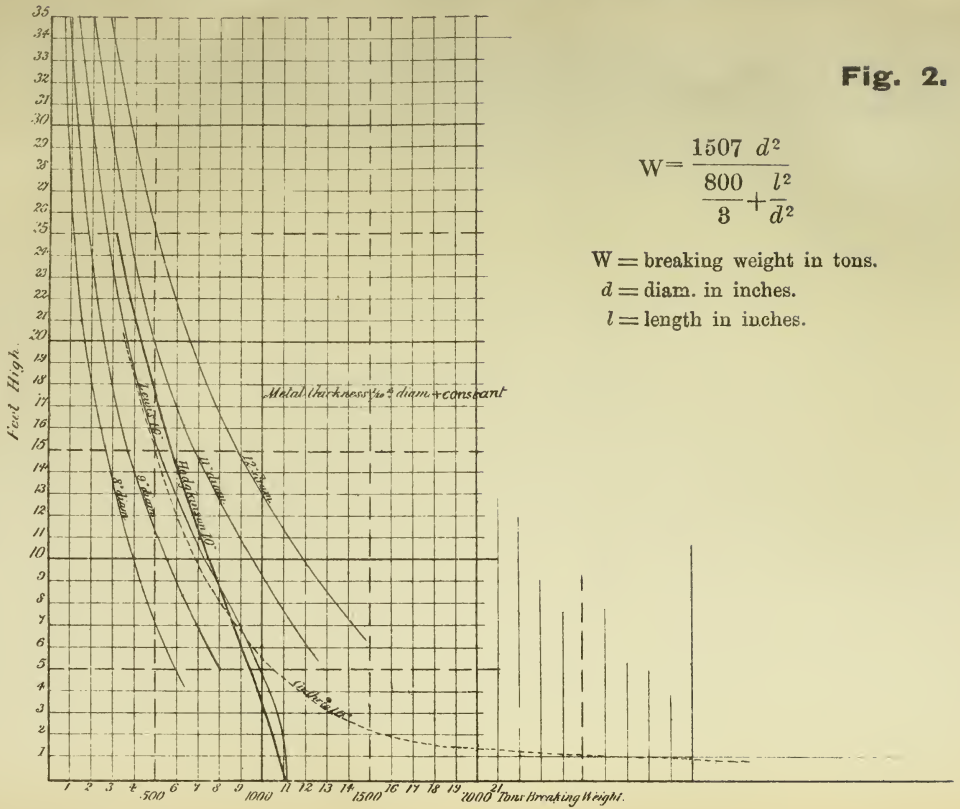

Fig. 2.

$$W = \frac{1507\ d^2}{\frac{800}{3} + \frac{l^2}{d^2}}$$

W = breaking weight in tons.
d = diam. in inches.
l = length in inches.

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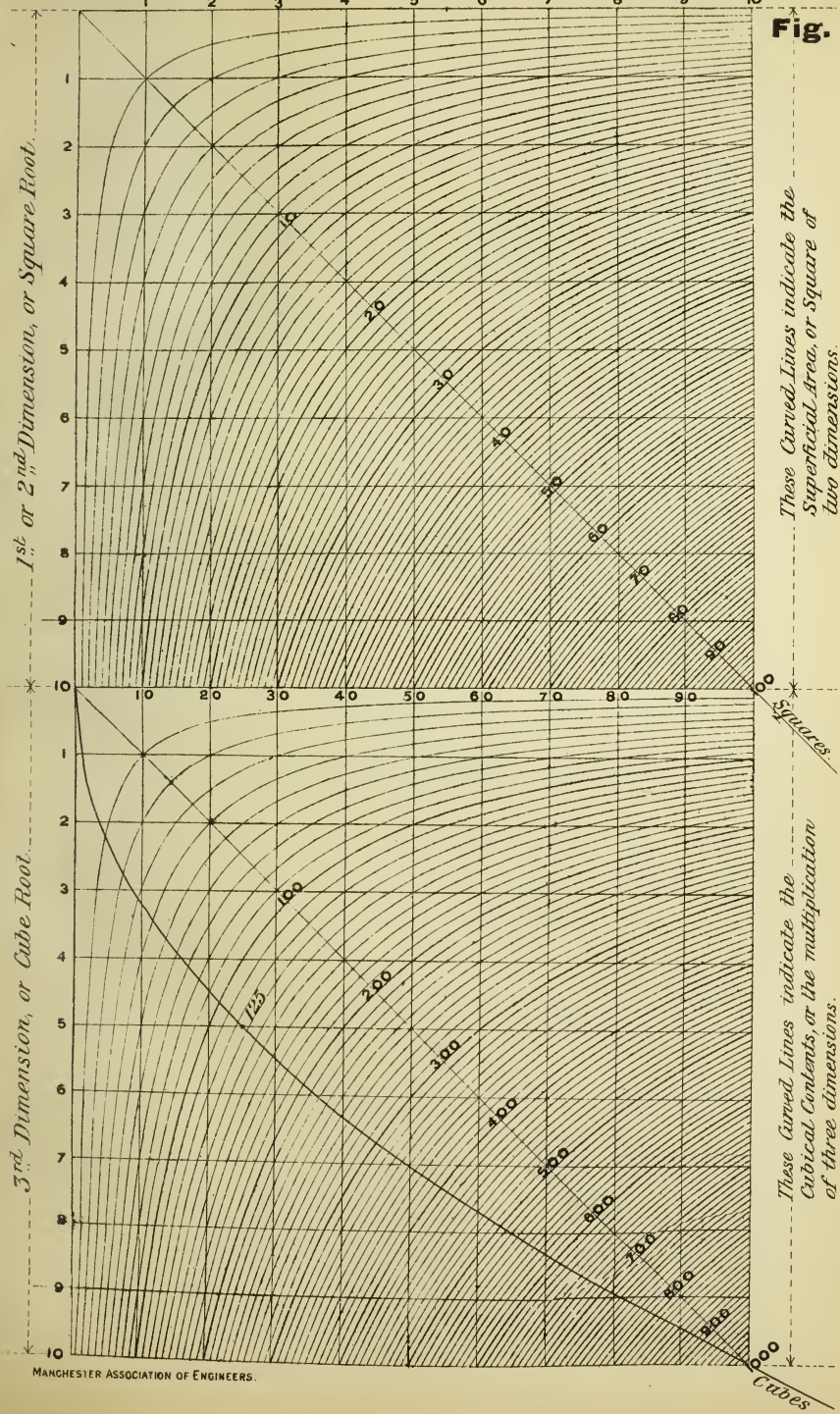
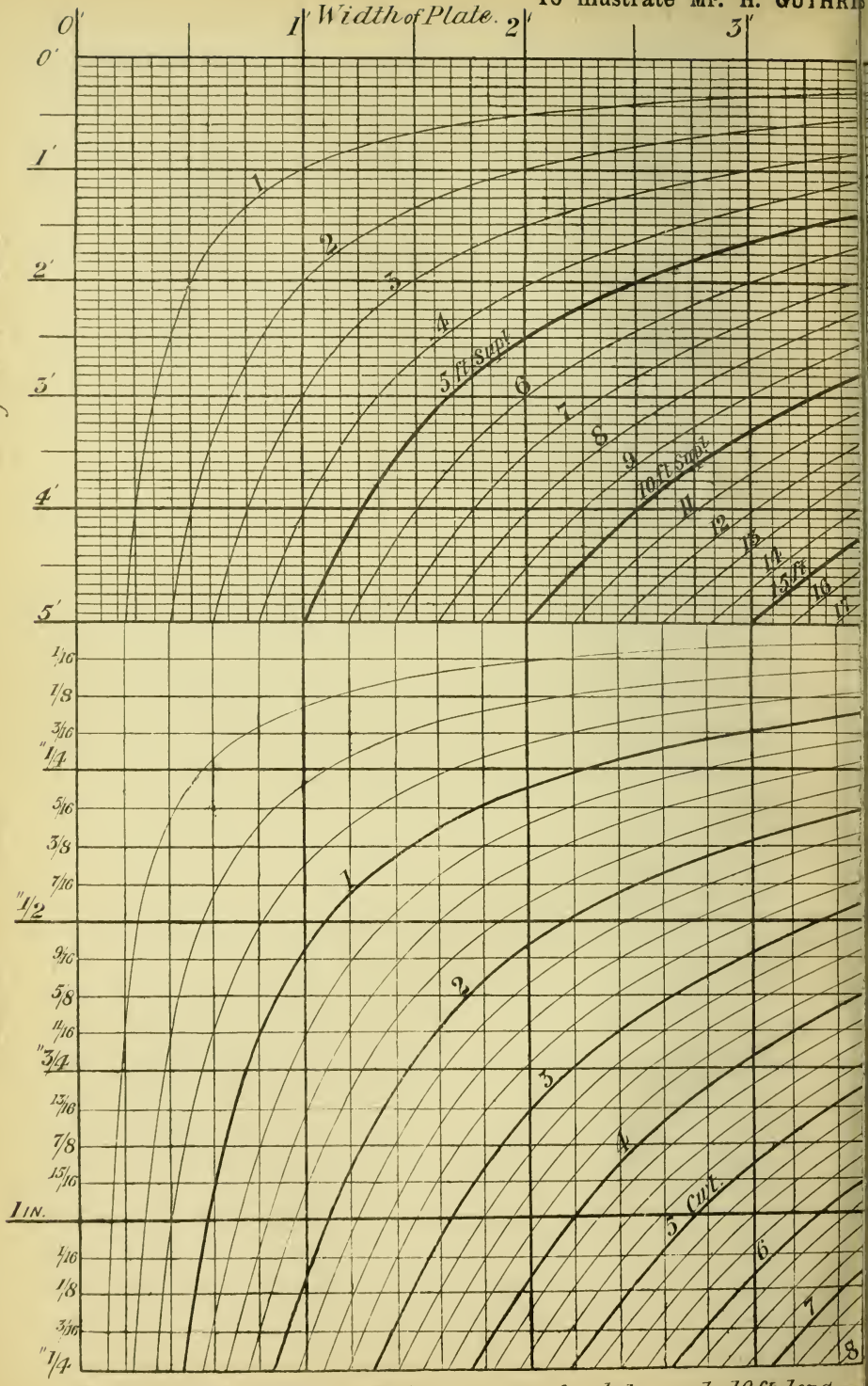
Fig. 3.


1st or 2nd Dimension, or Square Root.
3rd Dimension, or Cube Root.
These Curved Lines indicate the Superficial Area, or Square of two dimensions.
These Curved Lines indicate the Cubical Contents, or the multiplication of three dimensions.
Squares
Cubes
1 2 3 4 5 6 7 8 9 10
10 20 30 40 50 60 70 80 90 100
10 20 30 40 50 60 70 80 90 100
100 200 300 400 500 600 700 800 900 1000
1·25

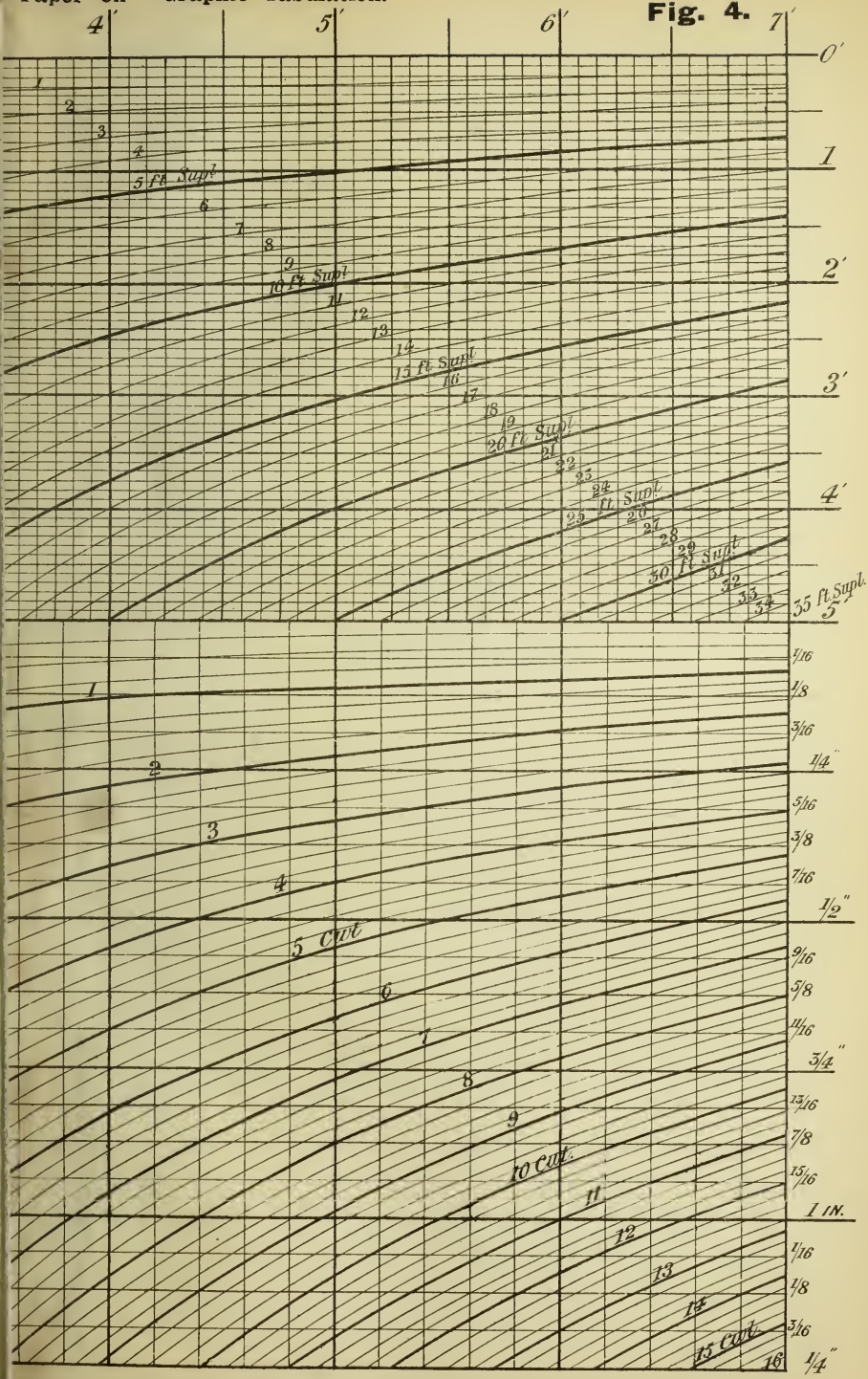
MANCHESTER ASSOCIATION OF ENGINEERS.

To illustrate Mr. H. GUTHRIE



This Table, with another sheet the same size, for plates up to 10 ft long,=

Fig. 4.



e than 147 pages of "The Ship builders' Assistant", with 102 199 readings.

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To illustrate Mr. H. GUTHRIE'S Paper on "Graphic Tabulation."

Fig. 5.

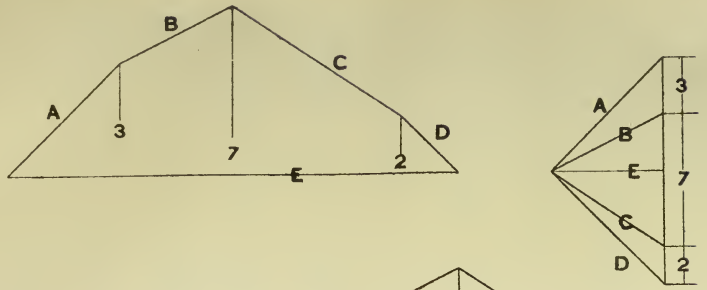
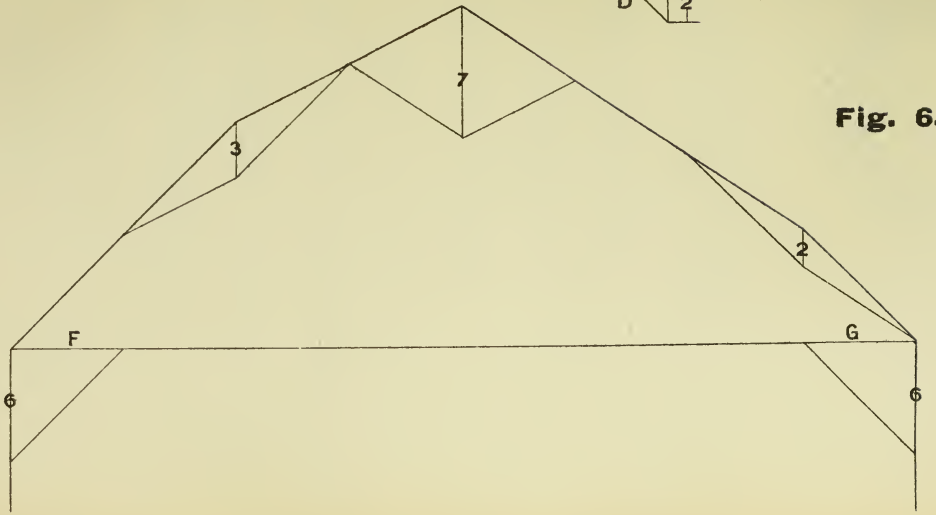


Fig. 6.



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AUTOMATIC EXPANSION GEAR FOR STEAM ENGINES.

A PAPER

READ BY

Mr. J. J. HARPER,

On 8th NOVEMBER, 1890.

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Mr. JOHN WEST, M.Inst.C.E., President,

IN THE CHAIR.

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AUTOMATIC EXPANSION GEAR FOR STEAM ENGINES.

Mr. President and Gentlemen,

In undertaking the task of preparing a paper on the above subject, to be read before the Manchester Association of Engineers, I was conscious of the great difficulty I should have in presenting to you anything that was novel, or that was not well known to most of the members. At the same time I was convinced that you would be pleased to have the most notable types of Expansion valve gear collected and compared as to their efficiency and economy as adjuncts to the steam engine.

I will not go into the history of the subject, but confine myself to a description of the most modern forms of gear.

Necessarily I do not mention a great many well known and efficient gears, because of the limited space and time that can be given to a paper such as this.

Before describing the mechanism for automatically regulating the supply of steam to the engine, I hope to be excused for comparing the principals involved therein as against the method of governing the engine, by throttling or reducing the pressure of steam, and the relative advantage of the former over the latter.

In engines fitted with "Automatic Expansion Gear" the steam valves are so controlled by the governor as to cut off the steam from zero, up to say five-eighths of the stroke, the cut off taking place earlier or later, to accommodate the varying resistance to the piston's travel and the pressure in the boiler; the object is to obtain the full boiler pressure at the beginning of the stroke, maintain it to the point of cut-off, and leave the rest of the stroke to expansion.

Although most engineers agree as to the superior economy of the automatic expansion (over that of the throttling) engine, yet I do not think it strikes the majority of the great saving in the expense of fuel there is, compared to those engines fitted with

gear wherein the point of cut-off is invariable relative to the stroke of the piston.

In the best possible type of throttling engine, on account of the bends and passages the steam has to pass through, the initial pressure in the cylinder seldom attains anything like the boiler pressure; the effect of this is that when a considerable load is thrown off the engine its speed is increased, on the contrary when an additional load is put on the engine its speed is diminished.

Now every stroke an engine makes above its normal speed is a waste of steam, and if the engine be large a vast waste of fuel takes place; on the other hand, a loss in speed reduces the production of a whole factory in direct proportion to that reduction of speed, the loss of one revolution in twenty reducing the capacity of every machine five per cent.

A variation of one revolution in five in a throttling engine is common, and in most cases is unavoidable.

There are some engineers who still think that this class of engine can compete with the automatic cut-off engine, but it is nevertheless a remarkable fact that they take every precaution to avoid throttling in the passages. Happily these relics of a by-gone age are becoming fewer in number. If the practice of estimating the efficiency of a steam engine by its consumption of steam were more common in this country than it is at present, we should hear very little of "throttling." The present practice of estimating the efficiency by the coal consumption (involving as it does the efficiency of both the engine and the boiler) is fair neither to the maker of one nor the other.

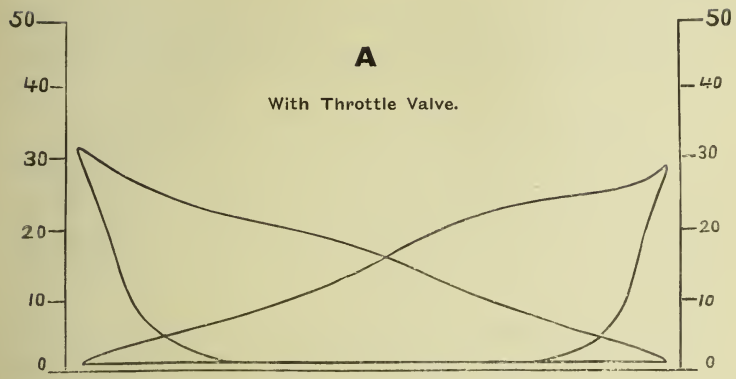
This has been pointed out again and again by writers, and with the number of trained engineers we have in Lancashire, who are capable of making such tests, it is surprising that it has not become the regular rather than the exceptional practice.

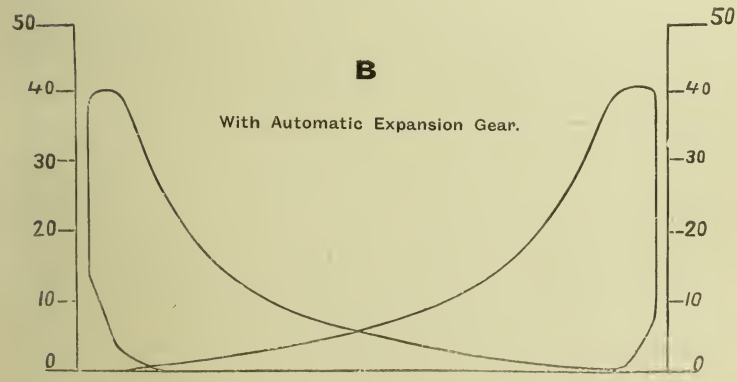
I give two diagrams, A and B, illustrating a typical case, and showing the advantage following upon the adoption of an automatic cut-off gear when applied to an engine previously governed by a throttle valve.

The steam consumption accounted for by diagrams, neglecting loss through radiation, etc. (which is assumed to be equal in both cases) gives a balance in favour of expansive working of about 20 per cent.

HORIZONTAL HIGH PRESSURE ENGINE.

Cylinders 20in. dia. Stroke 3ft. 6in. Speed 50 revs. per minute.





I am well aware that there are engines working and controlled by throttle valves which give a low consumption of fuel, but as a rule they are working under most favourable conditions.

I lately inspected one of this class in an Oldham cotton mill, admirable in every detail as far as workmanship was concerned. Engine and boilers were new, the latter being

placed as close to the engine as practicable. The consumption of fuel (common burgy) was 2·1lbs. per indicated horse-power per hour ; a portion of the steam however was used in heating the mill, etc., so that the precise amount due to engine I could not ascertain.

This engine was designed to suit the work, so that the load being practically constant the throttle valve was rarely in action.

Messrs. J. & E. WOOD'S VALVE GEAR. Figs. 1 & 2.

I have taken as the first arrangement to illustrate, the valve gear for Corliss Engines, patented by Messrs. J. & E. Wood, Victoria Foundry, Bolton, and applied by them to an engine for Messrs. A. & A. Crompton's Cotton Mill at Shaw, near Oldham.

When it is considered that this engine is capable of exerting 2,000 indicated horse-power, and that the valves of the low pressure cylinder are 7ft. 8in. long and 12in. diameter, it will be readily understood that it required no small amount of engineering ability to grapple with the question of valve gear successfully. The engine is a side-by-side compound, with an intermediate receiver. The high-pressure cylinder is 38in. diameter, the low-pressure cylinder 66in., the stroke of each being 6ft. The piston speed is 600 feet per minute, and the boiler pressure is 95lbs. When I saw the engines they were indicating 1,700 horse power. There are four valves, two exhaust and two steam, placed low down in the cylinder ; the pipes are kept out of sight below the floor of the engine house, not therefore in any way marring the appearance of the engine. The valve gear is actuated by a cross shaft between the engine frames, driven by gearing from the crank shaft. The steam and exhaust valves are worked by separate eccentrics, this method allowing a greater range of expansion than if one only were used. The steam valves are worked through double-tooth gripping pieces of hard steel, which give a length of bite of 10in., the release of these being regulated automatically by the governor in the case of the high-pressure cylinder, those for the low-pressure cylinder being regulated by hand to adjust the point of cut-off.

The "trip" or release of the steam valves is effected through inclined planes, moved by the governor in such a manner as to equalize the cut-off at both ends of the cylinder, and so compensate for the inequality due to the obliquity of the connecting rod. The section, Fig. 1, marked D, shows the inclined plane and the eccentric or crank E; it will be noticed that a ram K is carried by the slide block J, this ram on the upper side embraces the vibrating bar C; the lower side working on the inclined plane D, lifts the bar C clear of the gripping pieces, the valve *a* being closed sharply by means of a spring enclosed in a dashpot L, compressing air in the usual manner.

The inclined planes are worked from the governor by means of the rod F and levers G G. The exhaust valves *b b* are worked by means of the rod H. It is claimed for valves thus arranged that they are more compact, are better lubricated, and the clearances are reduced considerably; the first is very evident, the valves being placed below the cylinder, the top is left clear and all the gear is brought low down so as to be accessible and easily oiled. That the clearances are reduced is also evident, as two ports only are required in place of four, and as the lubricated steam on entering and leaving the cylinder passes over the exposed surfaces of both valves, it effectually lubricates the same.

These engines were tested by Mr. Neil McDougall, of the Boiler Insurance and Steam Power Company, of Manchester, who acted as consulting engineer for Messrs. A. & A. Crompton. The following is an abstract from this report:—

Mean indicated horse-power with four boilers at work, 1665·8; mean consumption of feed water per indicated horse-power per hour, 15·38lbs.; mean consumption of coal per indicated horse-power per hour, with slack at 6s. 4d. per ton, delivered in stoke hole, 1·896lbs.; with superior coal, 1·697lbs.

The set of diagrams taken from these engines shows that the distribution of steam is all that could be desired. The fluctuation of pressure in the receiver is seen to be very small. The receiver is nothing more than a large pipe connecting the two cylinders. The working of the gear is very easy, and all the wearing parts are of ample size, the pins being of steel, working in gun-metal bearings. The Moscrop recorder shows that the speed is practically constant.

Messrs. HICK, HARGREAVES & CO.'S CORLISS GEAR. Figs. 3 and 4.

The great feature in this valve gear is the opening of the port wide during the first tenth of the stroke, and keeping it full open until it is tripped, wire drawing thus being obviated for all grades of expansion beyond and including one-tenth of the stroke.

The valve gear is driven by shaft and gearing from crankshaft of engine, marked A, Fig. 3. On this shaft are two cams, one for each steam valve, marked B ; on the top of each cam there rides an arm or bracket projecting from a casting which carries the tripping gear, and slides on a vertical rod connected to the valve. This casting rises and falls with the cam, the upward motion commencing when the engine is on its centre, and being completed by the time the piston has finished one-tenth of the stroke. There is then a dwell or pause, due to a circular portion of the cam, and the casting remains elevated until it is again lowered by the cam. But in the meantime the *trip gear* comes into action, and breaking the connection between the casting and vertical rod upon which it slides, allows the valve to close with the suddenness peculiar to the Corliss Gear.

The tripping motion is worked by an eccentric on the side shaft marked D, through two links and a rocking lever E. It consists of a block or catch on the vertical shaft H, a catch lever F which engages with this block, and a second lever G which trips the first. The point of cut-off is determined by the governor, which turns the small rocking shaft D, as it rises and falls. The rocking lever referred to above as forming part of the tripping gear is mounted upon this shaft, but not directly, an eccentric bush being first keyed upon the shaft. The result of this arrangement is that when the governor rises the centre of the lever is moved in such a way that the acting end of the tripping lever is brought nearer to its work, and comes in contact with its companion lever sooner than before, cutting off the steam at an earlier point.

The vertical rod is connected to the lever of the steam valve by a block working in a slotted crosshead J, and is moved to close the valve by a spring, a dashpot preventing any concussion. The exhaust valves are also worked from the side shaft

by eccentrics. This gear is controlled by a Knowle's Supplementary Governor, which holds the rod working the trip gear rigid, so that the governor is not influenced by the jar when tripping, and regular turning is ensured.

AMERICAN CORLISS GEAR OF THE FRICK COMPANY. Figs. 5 and 6.

Figs. 5 and 6 illustrate a typical Corliss Engine of American design. This engine is manufactured by the Frick Company, Waynesboro, Pennsylvania, and presents many excellent features in its construction. Fig. 5 is an outside elevation showing the general arrangement of the gear. It will be noticed that the four valves are worked from one wrist plate (a feature common in American engines), consequently only one eccentric is required.

Four short rods transmit the motion from the wrist plate to the steam and exhaust valves; the latter having a constant motion, whilst the former are capable of being closed by trip gear at any part of the travel, and so cut off steam as required. The method in which this is done is shown in Figs. 5 and 6. On the valve spindle is keyed a lever *b*, carrying on one end a hard steel hook stud *f*, with four working faces; to this lever is attached a rod communicating with a dashpot K, which tends (by the pressure of the atmosphere) to keep the valve closed. Working loose on the valve spindle is a lever *a*, carrying with and pendent to it being a latch lever *d*, provided with a hard steel catch piece *e*; when the wrist plate is moved in the direction of the arrow it moves with it the lever *a* and latch *d*; the die *e*, carried by the latter engages with the hook stud *f*, and is kept in contact by a spring at the back. When the reversal of the wrist plate takes place, the valve is opened by the lever *a*, carrying the lever *b* along with it until the latch *d* comes in contact with the cam *l*, on governor lever *i*. These cams are adjusted by the governor so as to give an early or late cut-off as required. Fig. 6 shows a cross section of cylinder through the valves, Fig. 6A being part of a longitudinal section through cylinder and valve boxes. The valves are so arranged as to take up their own wear, and in case of need act as relief valves; they are separate from the valve spindles, thus avoiding splitting

of the valve, or distortion ; end play and rattling are prevented by springs as shown in Fig. 6.

The valve stems are made of deoxidised phosphor bronze, as are also the glands, trunnions, shoes and springs. The dash-pots K are of the vacuum type, that is to say, when the piston is raised a partial vacuum is formed underneath, and directly the "trip" gear comes into action, closes the valve *instantly*.

RAMSBOTTOM'S VALVE GEAR. Figs. 7 and 8.

Figs. 7 and 8 show plan and elevation of valve gear of novel design, patented by Mr. John Ramsbottom, and applied by Mr. Benjamin Goodfellow, of Hyde, near Manchester, to a pair of horizontal compound tandem engines, for Mr. John Mayall, Mossley.

The indicated horse-power of these engines is 915·9, the diameter of each high pressure cylinder is 28in., and each low pressure cylinder 52in., all 6ft. stroke. Fig 7 shows the trip gear only, the exhaust valves being worked from an independent eccentric, not shown. V^1 and V^2 are the spindles of the steam valves upon which are keyed double ended levers, one end O being attached to the ram of dashpot P, the other end being attached to a "toggle" lever N. Movement is given to the valves by means of the rod Q, worked by an eccentric and levers in the usual way. If the rod Q is moved in the direction of the arrow the valve V^2 is opened for admission of steam, the valve V^1 remaining closed until the return stroke, by virtue of the toggle lever N^1 being inoperative during the stroke from left to right. If the valve V^2 were opened and closed and coincided with the movement of the rod Q, it would have a constant cut-off dependent upon the movement of eccentric.

To make the cut-off variable a hanging arm K, sliding on a rod L (regulated as to position by the governor through the rods Y Y and lever B B), comes in contact with the trip arm M, which raises the joint N ; directly this is over the centre the jointed lever is doubled up by the action of a compressed spring in the dash-pot P, and in so doing closes the valve suddenly. The position of levers is clearly shown (when the valve is closed) on the left of Fig. 7.

In the event of the engines racing a stop motion is provided, and worked from the governor through the rod I. A weighted lever D working on the shaft A is held in position by a bell crank H, with a snug on the end. Lever F and rod G are provided for throwing the rod C out of gear with lever B, when the governor lifts the catch H.

When the engine races the rod I lifts the catch H, the weighted lever D lifts the rod C clear of lever B by means of levers F and G; the lever B is free to move on pin A with a movement equal to the ordinary rise of governor, a slot X allowing of this; when however the lever D falls the key moving in slot X gears with lever B, drawing it round in the direction of arrow, and moving the hanging arms in towards the tripping levers M M by means of the rods Y Y, so that the valves cannot be opened on account of the trip motion coming into action at the beginning of stroke. A buffer is provided at J for the weight E to fall upon. This gear is unique in one respect (so far as I am aware), that is, it does not engage and disengage with a clutch at each stroke of the engine, which is a step in the right direction, especially so for quick running engines. It also has another good point, in the fact that there is no re-action on the governor when tripping.

These engines were tested by Mr. M. Longridge, June 13, 1884, and the following is an extract from his report:—The total weight of coal used for 8·28 hours was 12,452lbs., plus 256lbs. used to replace the fuel drawn out of the furnaces when cleaning the fire at dinner time. The average indicated horse-power calculated from diagrams taken half-hourly was 888·35lbs consequently the consumption of fuel per indicated horse-power was 1·69lbs. As the coal contained 8 per cent. of ash the consumption of pure coal per indicated horse-power per hour would be 1·56lbs.

"THE WHEELOCK VALVE GEAR." Figs. 9, 10 and 11.

This gear, the invention of Mr. Jerome Wheelock, shown in Figs. 9, 10 and 11, is very much like the Corliss engine in appearance, but the valves all being below the cylinder it does away with the unsightly appearance of the square corners on the top of cylinders.

Formerly the valves were of the oscillating type (or Corliss pattern), but now whilst the valve is retained in form it merely serves as a seat for grid slide valves. The travel of these valves is very small, the motion is effected by means of the links *b b*, Figs. 10 and 11, and levers *d d* fast on the valve spindle C, made to oscillate in bearings T T. The collar U is forced against its seat by steam pressure, making a tight joint. The four valves are actuated by a single eccentric from the crankshaft through the rocking levers B, which being keyed on the valve spindle cause the valves to oscillate with the motion of the eccentric. A "gab" end is formed on the eccentric rod D so that the rod can be lifted clear of the valves, which can be worked by hand on starting. The lever B carries at F a pin, made eccentric for adjusting the cut-off valve. The valve A serves for both admission and exhaust, the valve D giving a variable cut-off dependent on the governor, the manner in which this is effected being as follows:—The curved lever B carries at the point F, and pendent to it, the detent G and the guide lever H, the under side of the detent supporting a steel plate K, which gears with a cubical steel block sliding on the guide H and oscillating on the pivot I. The weight of fork lever is sufficient to keep it in gear with the steel block, so as to draw it by the steel plate in the direction of the arrow, and with it the lever J, actuating the slide of the valve B until the projection M on lever L comes in contact with the detent fork, lifting it clear of the block F. The valve is suddenly closed by means of the spring and weight P through the pivot Q on the lever. The earlier or later action of the "trip" being regulated by the governor through the lever L and rod O, a spiral spring is provided at R for altering the action of the governor, which can be done whilst the engine is running.

If the belt slips off the pulley of the governor, or any other accident happens to it, another projection N comes in contact with the detent fork, lifting it clear of the block and so preventing further admission of steam. The great ease with which a valve can be taken out and replaced is a strong point in favour of this gear. In the event of the gear at one end of the cylinder being deranged, it is said that the engine can be worked single-acting, this having been done at a public trial. No doubt the engine would be lightly loaded.

THE RICHARDSON, ROWLAND PATENT VALVE GEAR.

Figs. 12 and 13.

The sole makers of this gear are Messrs. Robey & Co., Lincoln. It presents some features of great interest, and unlike most gears with stamper valves is very simple and direct in its action.

As shown in Fig. 12, the admission valves are of the double beat lifting type, one for each end of cylinder. These are situated close to the extremities of the piston's travel so that the clearance is reduced to a minimum, allowing the piston to begin its stroke with the full benefit of the boiler pressure.

Referring to the cross section of the cylinder (Fig. 12) it will be seen that the small eccentric rod K is enabled to act upon the valve A (which is in equilibrium) by depressing the outer end of the lever B, and so raising the valve. This occurs just before the commencement of the stroke, owing to the different arcs described by the end of the eccentric rod and the lever B respectively; at a certain point the tripper L slips out of contact and the valve drops instantaneously, cutting off the steam supply. To prevent the valve being injured by coming too heavily on its seat the spindle is prolonged upwards, and terminates with a small piston within an air cylinder F; a small air cock, G, at the bottom of the cylinder regulates the descent, so that the valve falls rapidly but without concussion. This is the whole of the mechanism concerned in the admission and cut-off of the steam at fixed points of the stroke, and for the low-pressure cylinder this is all that is required.

To vary the point of cut-off in the high-pressure cylinder however by the action of the governor a special arrangement is necessary. Figs. 12 and 13 show this arrangement which is simplicity itself.

The governor in rising moves the lever arm, and with it the pivot or fulcrum K of lever B, which has the effect of causing the tripper L to lose its contact, and the valve to fall on its seat at an earlier period in the stroke, and thus as the governor rises and falls the point of cut-off is sooner or later accordingly. It will be noticed that the long horizontal arm of lever is prolonged past the governor and that a small cord is attached to it; this cord may be led away to any part of the build-

ing, and forms a ready means of instantly stopping the engine (in case of emergency, as in the case of accident to life or machinery). By pulling the cord the lever O draws the valve lever B completely clear of the trippers when of course no steam can enter the cylinders, and the engine, which may have been exerting a thousand horse-power, may be brought to a stand at once by the touch of a boy. With so sensitive an apparatus as this, accurate governing is easy of attainment, and a small and simple centrifugal governor fulfils every requirement. When the engine is used for electric lighting the Richardson Nevile electric governor, Fig. 13, is applied to the governor levers and the speed is regulated by the electric current itself, thus enabling a constant current or constant E.M.F. to be maintained with varying loads. We now come to the exhaust valves which are placed underneath the cylinder, and like the inlet valves close to the cylinder to reduce the clearance. Referring to cross section, Fig. 12, they will be seen to consist of the gridiron type of slide valve, sliding on a treble ported face or seat formed upon the upper surface of the exhaust "bonnet" and worked by a small eccentric upon the longitudinal shaft H, the same shaft actuating the inlet valves and the governor.

These valves having a short travel and the pressure of steam being practically nil at the points of closing and opening same, the power absorbed in working them is very small.

From the position of the exhaust valves beneath the cylinder the latter is effectually drained of any water which may enter with the steam or arise from condensation. The valves are also peculiarly accessible for repairs or examination, as by removing the cover R, Fig. 12, and loosening the lock nuts from the spindle the valve will drop out into the hand without interfering with any pipe joints. The exhaust branch can also be removed without disturbing the remainder of the exhaust pipes.

TRAPPIN'S VALVE GEAR. Figs. 14, 15 and 16.

This gear, which was introduced into England by Mr. H Simon, of Manchester, presents the usual features of the Sulzer engine so far as the valves are concerned, the difference being in the method of "tripping" the valves by means of the governor's action.

A side shaft A driven by gearing from the crankshaft has four small eccentrics keyed upon it, two B B for working the steam valves, and two C C for the exhaust.

The admission eccentrics have short rods, the ends of which are connected to rocking arms D, moving freely about a fixed centre E. On each eccentric strap is formed a steel-faced lug F, the point of which describes an irregular oval. The path of this point is described in the diagrammatic view, Fig. 16. The valve is opened by F coming in contact with a hardened face on the connecting rod G, which can be moved to or from the eccentric by the action of the governor through the link J and lever H on the governor layshaft L. Fig. 16 shows the gear when the governor is in its highest position, and it will be noticed that the lug F is just clear of the connecting rod G, the governor having therefore entirely cut off the steam.

The numbers in Fig. 16 show that as the governor balls fall, the rod G is moved in towards the eccentric, the lug F coming always in contact with it at the same instant, the engagement lasting longer and longer as G is moved in up to 0·8 of the stroke, the latest cut-off for which the gear is set. The governor therefore, has complete control of the cut-off from 0 to 8-10ths of the stroke, with a very small motion of the arm H. Whilst the parts are proportioned so as to reduce the velocity with which F strikes G, the surface of contact is comparatively large. The valves, when released, are closed in the usual manner by springs placed in boxes over them, the lower portion of the spring-boxes forming dashpots.

The exhaust valves are given a constant motion by means of the eccentrics C.C. and are brought to their seats by a spring as shown, the whole arrangement forming a very simple and effective piece of mechanism.

THE PROELL COMPULSORY GEAR. Figs. 17 to 20.

The use of double-beat equilibrium valves has made such progress (especially on the continent) that I think any description of expansion gear would be incomplete without noticing the very beautiful and ingenious arrangement patented by Dr. Proell. In this gear it is made practicable to use stamper valves on the largest class of engine, there having been a limit to the size

of valve used when it is allowed a free fall at the point of cut-off. A large valve presents difficulties as to its efficient cushioning in falling, and for engines of large size it is necessary that both the opening and closing of the valve shall be regulated by the gear; or in other words, that the valve should be opened and shut by a permanently guided or "compulsory" motion. The solving of this problem has been essayed by several inventors but with complicated results, the gear under notice being a striking exception. Fig. 17 shows an outside view of the gear, and Fig. 18 a diagrammatic sketch (showing the principal involved therein) divested of constructional details. On a side shaft, driven in the usual way by gearing from the crank shaft, are eccentrics for working the steam and exhaust valves, the former are kept to their seats by a laminar spring, the latter by a spiral spring. In Fig. 18, C represents the path of the eccentric, the triangle *a*, *b*, *c*, being an extension of eccentric strap. Whilst the point *c* describes a circle, the point *a* oscillates about the fixed point *k*, and the point *b* describes a pear-shaped curve in a regular and firmly guided manner. Now if we make this point *b* to slide against the hanging arm of a bell crank lever, to the other arm being attached a rod communicating with the valve, the valve will be opened and closed in a constant manner relative to the crank path.

By the addition of two parts, the link *l* and the ram *g*, the gear has been made to give a variable cut-off. The link *l* is pivoted at one end *b* to the bridle, and at the other to the governor rod at *x*, the tappet rod or ram *g* is also pivoted to the governor rod at *x*, and at the other end is free to work through the movable sleeve *n*, which is pivoted on the bell-crank that actuates the valve rod. The striking point of the tappet rod is determined by lock-nuts at *d*.

In practice it has been found more convenient, instead of the ram *g* working into the sleeve *n*, to attach the tappet rod to the end of another bridle rod, as shown in Fig. 17 and Figs. 20A, B, C and D, where it is marked *b*—*i*, and this bridle rod leans itself gently and without shock against the arm of the valve lifter, thus ensuring noiseless working. The influence of the governor on the variation of the cut-off will be seen from Figs. 20B, C and D, while Fig. A shows the gear during its inactive

return stroke. It will be observed that in all positions of the governor the point *b*, where the valve lifter is attacked by the gear, remains the same, *i.e.*, the gear insures a *constant lead:* the lower, however, the governor rod holds the point Z the larger will be the proportion of the curve *m*, described by the point *b*, which is utilised for opening the valve. In the sketches the position of the point *c* always corresponds with the relative positions of the points *a* and *b*, and c^1, a^1 and b^1 correspond, as also do c^2, a^2 and b^2 in Fig. 20D. That part of the curve *m*, which is passed by the point *b*, and during which the valve is held open, is drawn out thick. At the point b^1 the pressing lever *b*—*i* leaves the valve lifter, and from the three diagrams, B, C and D, it will be seen that the cut-off, as represented by the travel of the eccentricity at *c*, is variable between very little and over three-quarters of the stroke.

During the time the valve is open it is rigidly held between the gear and a strong closing spring, while when the point *b* has arrived at b^1 the valve is seated again. It will be further seen that the opening and closing of the valve takes place at periods when the point *b* travels fastest, and therefore a comparatively quick admission of steam and a quick cut-off takes place. Owing to the short lift required by the double-beat valve the movements of the gear are also short and decisive, and the moving parts are subjected to the least possible wear. This gear and the engine generally are admirably worked out. The makers are prepared to guarantee the maximum of steam consumption in every case, under an agreed penalty of £25, for every quarter of a pound of dry steam per indicated horse-power per hour used in excess of the guarantee.

Messrs. Sulzer Bros., Winterthur, having been probably the first to introduce the double-beat valve in combination with a trip gear, the invention of Mr. Charles Brown (at that time their manager), are perhaps able to speak with more authority as to the durability and merits of this valve than any engineers in the world

The valves are made of a special mixture of hard *cast iron*, ground to their seats, the greatest care being taken in the workmanship.

A valve was exhibited at the Paris Exhibition which had been in constant use for fourteen years without being ground, and was still in good condition for working. Messrs. Bryan, Donkin & Co., are the makers of this engine in England.

PETRIE & DOWELL'S VALVE GEAR. Figs. 21 to 25.

Manufactured by Messrs. John Petrie & Co., Phœnix Foundry, Rochdale. This arrangement consists of two piston valves, one at each end of the cylinder, Fig. 21, *d d*, having a plain edge to regulate the exhaust, the other end having openings corresponding with a similar number of openings in the valve casing C C.

By the partial rotation of the valves the steam can be cut-off by the bars in the valve covering the openings in the casing. Rectilinear motion is imparted to the valves in the usual manner by an eccentric and rod, squares are formed on valve rods at e^1 and e^1 working through bushed cranks held in brackets Z Z. Motion is given to these cranks so as to rotate the valve rods when required to cut-off the steam.

The valves are free to move independently of one another, this being accomplished by the valve spindles having collars on the ends at *g*, Fig. 21, with lock nuts *j j*, and split glands *h h*. The method in which steam is cut-off at any part of the stroke is as follows: Upon the shaft S (which is driven from the crank shaft by gearing in the usual manner) are mounted two cams *t* Figs. 22 and 23, one cam for each end of the cylinder. On the guides *v* and *y*, slides a casting *w*, actuated by the cam *t*, and carried by this frame is a block *x*, capable of being moved in or out, and provided with a catch x^1 which acts upon the hardened steel projection y^1, carried by rod *y*, this rod being connected by suitable means to the cranks *z z*, and when lifted rotates the valve or valves by means of the squares on valve spindles e^1 e^1.

On the shaft *s* are mounted eccentrics 5, 5, which through the rod 3 and lever 4, give a rocking motion to the rod 1, carrying a bowl working on the inclined lever 2. This lever is moved against the tension of a spiral spring in one direction, and the governor regulates through the rod 7, the position of the bowl on the inclined lever 2, moving it against the spiral spring and drawing the block x^1 out of gear with catch y^1

allowing the rod *y*, to fall and cut-off the steam to the cylinder. The rod *y* is in connection with a powerful spring, and a dash-pot is provided to prevent shock and the valves being closed too suddenly. I had the pleasure of inspecting this gear as applied to a pair of engines indicating 1,303 horse-power at the B mill of the Crawford Spinning Co. Limited, Rochdale; it works without noise, and gives a perfectly good diagram. The turning is excellent, practically a straight line being drawn by the Moscrop recorder. I was informed by the engineer that he had no trouble with it, and a valve after working five years had no perceptible wear, and its surface was like burnished silver.

A modification of this gear as applied to an engine, also at the B mill of the Crawford Spinning Co. Limited, Rochdale, is shown in Figs. 26 and 27, with the accompanying indicator diagrams taken therefrom.

Upon a shaft between the valve boxes is fixed a cam revolving at the same speed as the crank shaft of the engine, but in a horizontal plane. This cam causes a frame *b*, mounted in suitable guides, to be traversed longitudinally; to this frame are fixed catch-pieces which engage with corresponding catch-pieces on the rods connected to the levers C C, for turning the valves to admit steam. To this sliding frame are attached "trip" levers *d d*, for disengaging the catches before referred to, the ends of these levers being curved so as to come within the range of a cam or disc *e*, by which the "time" of the cut-off is regulated; this is rotated by the shaft *a*, and is connected to the governor in a suitable manner, and is raised or lowered thereby in the slot formed in shaft *a* marked F, and thereby puts the cam *e* in a position to trip either one valve or the other, sooner or later, as the case may be. When the valves are tripped they are closed sharply by means of a spring acting through the rods G G, and dashpots are provided to regulate the descent. Both engines are finished in a neat and satisfactory manner.

THE PORTER ALLEN VALVE GEAR. Figs. 28 to 32.

In this gear we have an automatic variable cut-off, effected by positive movements. The link, as shown in Figs. 28 and 31, is driven by a single eccentric, and from suitable points admission and exhaust valves are actuated.

The Porter governor regulating the position of the block in link (and thereby the quantity of steam to suit the varying resistances) by changes in the speed so minute as to escape the sense of sight. As usually now made the cylinder has four valves, two exhaust and two admission valves.

It will be noticed that the steam or admission valves are equilibrium slide valves of a peculiar but important type, with a back adjustable pressure plate, Figs. 29 and 30, marked *a*; the plate is of a section suitable to resist the steam pressure without springing, and is held by this pressure against two inclined supports, one above and one below the valve, and is supported by a bolt screwed through the bottom of steam chest.

If this bolt is slacked it allows the steam to force the back plate on the valve and seize it. By turning the bolt in the opposite direction the back plate is moved away from valve, so that each valve can readily be tested for leakage by unhooking the disengaging hook, shown in Figs. 28 and 32, marked *b*, and working the valves under steam whilst an attendant adjusts the back plates.

This has been found to be a very useful feature in this engine, and would be a valuable adjunct to several so called equilibrium slide valves that are now on the market. It is difficult to say how it comes about that wear takes place in this valve, as it is in equilibrium, both as to pressure and flow of steam, and as this wear does not take place in every case it points rather to chemical than mechanical action.

The exhaust valves are clearly shown in section, Figs. 29 and 30, a noticeable feature being the method of draining the cylinder by means of the exhaust port being below the bottom of cylinder.

These valves are of the "gridiron" type, working under the pressure of steam in cylinder, having a small movement and giving four openings for release. The valve seats are formed on covers, upon which the outlets are also cast, marked C C, Figs. 29 and 30. The distribution of steam in this engine is admirable in all respects. The release of the steam being one of its most remarkable features, the movement of the exhaust valve being most rapid at the instant of release; the steam can be held to almost the end of the stroke, and yet the port be opened to the full width by the time the crank reaches the line of centres.

Galloways Limited, Manchester, are the makers of a modification of this gear, which is much simplified. The valve arrangement consists simply of two slides, and in the compound engine the exhaust valve of high pressure cylinder serves as the induction valve for the low pressure cylinder. The inlet valve of the high pressure cylinder is simply a flat plate or grid valve with a number of openings in it, consequently with a slight movement a large area of opening is obtained. The travel of this valve is made variable by means of an oscillating link and a slide block connected to the governor, the motion being so arranged that the lead remains constant with the variation of travel. The distribution of steam in high pressure cylinder is controlled by Galloways' high speed parabolic governor. An engine with this gear has been at work for years in the mill of Messrs. Houldsworth and Gibb, Eccles, and gives every satisfaction. The turning is perfect, and the gear working without noise gives the observer a very favourable impression as to the durability of the mechanism.

I have not given a drawing as the gear is so well known already.

It has given me very great pleasure to read this paper before you ; the subject is so wide however, that I feel I have done but scant justice to it. The result of my efforts being much restricted I have only been able to notice a few of the arrangements in vogue, but I am sure you will agree with me that some, if not all, exhibit a wonderful amount of ingenuity and mechanical skill, and whilst some of the inventors have lost sight of the fundamental law of mechanism (simplicity) others have reduced the number of working parts to what almost seems the lowest possible limit.

Fewness of parts, strength combined with lightness, large wearing surfaces, accessibility for oiling and getting at the valves, seem to me to be the leading features the designer should have in view. If we have a great number of parts for the centrifugal action of the governor to overcome we may be absolutely sure that we shall not have an effective valve gear, and the cost in repairs and loss of time may very probably absorb whatever saving there may be in increased economy of fuel.

The jar caused by tripping should not come directly on the governor, but by suitable means the tripping cams should be held rigidly in position, and so let the blow come upon a screw and nut instead of on the governor, as in the Knowles Auxiliary governor, made by Messrs. Hick, Hargreaves & Co., Bolton. The valves should be in equilibrium (or nearly so), and the clearances kept as small as possible.

The introduction of the electric light makes the necessity of automatically regulating the steam engine of the greatest importance, and I hope in the discussion that will take place we shall have the opinion of gentlemen upon this subject who have made it their special study.

DISCUSSION.

Mr. G. B. Goodfellow said the principal subject in connection with the steam engine, the valve gear, had been brought before them in a very able manner by the writer of the paper.

Referring to the manner of describing the duties of a steam engine, he said it was common enough for people to say that an engine used a certain quantity of coal, and it was only recently he impressed the fact upon a customer that an engine consumed steam and not coal. In his opinion it was important that steam users should be induced to judge the engine and boiler separately on their merits, and then they would be able to apportion the blame, or reverse, to the engine maker or boiler maker respectively. As regarded the efficiency of boilers, certain tests were made of them, and it was generally assumed such boilers would always give the same results; whereas, as a matter of fact, the effectiveness of the boiler depended on the way it was fitted up, the quality of coal supplied, and on the attention given to it.

Respecting the throttle-valve engine, Mr. Harper would perhaps excuse him if he observed that, when mentioning the loss of initial pressure sufficient stress was not laid upon the fact that the throttle valve, to be of any service, must be a throttler, irrespective of the bends and shapes of the pipes and ports; there must necessarily be a certain amount of wire drawing

before any good accrued, still with a throttle valve properly constructed and wide open, a fair initial pressure might be obtained.

Respecting the compound and other engines where the exhaust and steam valves are connected to one port, he did not think it was a good plan. It was a mode adopted by several makers, and at first sight it would appear that much less clearance could be got in the ports and passages by such practice. However, if it were carefully worked out it would not appear so advantageous; the great evil in connection with it was that the condensation which took place in consequence of the hot and live steam having to pass through the same port that the exhaust steam had already passed. The latter necessarily cooled the port, and the hot steam was thereby condensed and moistened. Again, the bottom part of the cylinder was always wet. To his mind, it was the better way to have the steam port at the top, and the exhaust port at the bottom of the cylinder. Certainly this method did not produce the nicest looking engine, but of course engineers often had to construct ugly machines to achieve the best results.

Referring to the Goodfellow valve gear, he said the engines referred to in the paper were among the first he made with that trip motion. The great advantage in that motion was that while the pressure was upon the valves there was little or no motion whatever upon the smaller pins of the tripping link, those were nearly as possible stationary in their bearing; directly the tripper came in contact with the finger worked by the governor the tripper link was lifted slightly above the straight line, and immediately it got about $\frac{1}{16}$th above it the spring closed the valve, so that when the motion in the link occurred there was little or no weight on it. He had had this gear working on an engine running at 110 revolutions for a considerable time without the pins being perceptibly worn.

In reference to the grid-iron slide valves of the Wheelock engine, he thought sooner or later there must be considerable trouble in keeping the edges up to the mark, and as engines ran at higher speeds the difficulty would be increased. In regard to the Cornish or double beat valves, he thought for small engines they were admirable, and he was surprised that Lancashire

engineers did not give more attention to that class of valve for such engines; the valves were effective in their working, conveniently made and easily adjusted.

Concluding, Mr. Goodfellow said it was in the interest of engineers generally and steam users, that a better class of men should be obtained to take charge of the steam engine, upon which so much care and trouble had been spent. The points they ought to watch in designing a first-class engine, so far as the economical use of steam was concerned, should be to reduce the clearance at the ends of the cylinders and in the steam passages, further that the steam shall be distributed in such a manner as to have as little as possible condensation in the cylinders.

Mr. James Hartley said he must preface his remarks by saying that he was not in favour of throttle valve engines, believing that it was best under most circumstances to apply automatic expansion gear to single cylinder engines, also to the high-pressure cylinder of a compound engine, and it might also in some instances be advisable to apply it to the second cylinder of a multiple compound engine.

He thought Mr. Harper had not chosen (by a long way) the best diagrams for illustrating either the throttle valve engine or the one with automatic expansion gear. In the 7th paragraph Mr. Harper says, "in the best possible type of throttling engine the initial pressure in the cylinder never attains anything like the boiler pressure." If we must accept the diagrams shown as the best that can be obtained, this is so. He, Mr. Hartley, was prepared to show them *three sets* of diagrams, two of which, Figs. 33 to 36, were taken from the high-pressure cylinders of McNaughted beam engines, which with a very late cut-off, show the initial pressure not to be very much below the pressure existing in the boiler at the time they were taken. The other set, Figs. 37 and 38, was from a single non-condensing engine, which also proved that when the steam pipes and passages were of sufficient area, a pressure could be obtained in the cylinder very nearly coinciding with the pressure in the boiler. On the engines from which these diagrams were taken there was no expansion gear of any kind, simply ordinarily lapped slides.

He thought the gentlemen present would admit that it would be madness for any firm to apply automatic expansion gear to those engines unless the cylinders were changed, and which would mean as far as engines from which diagrams Nos. 33 to 36 were taken, the renewal of both high and low-pressure cylinders; and it must be borne in mind that it was no light task for a firm to renew cylinders of 40in. or 50in. diameter, *to save what?* Practically nothing in the cases just mentioned.

He would show them a combined diagram, Fig. 43, from a compound condensing engine, being one of a pair of tandem engines driving a cotton mill, having nothing but lapped slides, and although the vacuum was not so good owing to hot injection water, the coal consumption was not more than 2lbs. of coal per horse-power per hour. Some little steam was also used for heating the mill; the diagrams were taken in March.

He was sorry to add that these engines were not now working so satisfactory nor so economically as when these diagrams were taken, owing no doubt to a change made in the attendant. In the latter respect he could only emphasize the remarks of Mr. Goodfellow on the importance of having only the best possible men to take charge of our steam engines, if economy were desired by the owners. Nothing was more painful to him than to see a good engine ruined in every sense, simply because the owner objected to pay a good man who understood his duties, choosing rather to have his engine ruined, and ten times the amount he saved in wages thrown away in fuel, through employing an incompetent and consequently a cheap (?) man.

Mr. Harper also says that good or satisfactory turning cannot be obtained in throttle valve engines, a variation of from one in five to one in twenty being common, even in the best cases.

He, Mr. Hartley, begged to say that he knew many instances where equally good turning was obtained by throttle valve engines as by any engine which had automatic expansion gear on, for with a many of these bad turning was found.

A great many people wondered how it was that such economical engines existed with nothing but throttle valves and lapped slides, but the reasons were not far to seek, as the firms who had these engines were satisfied with a low grade of expansion, whilst a great many makers of engines with automatic

expansion gear went in for a high grade of expansion, consequently what they gained by expansion they more than lost by condensation, during admission and expansion. With reference to the diagrams shown by Mr. Harper from the engines of Messrs. Crompton, of Shaw, he was sure they did not fulfil the conditions that Mr. Harper tells us we should expect from engines with automatic expansion gear on. It would be observed that from 4lbs. to 4½lbs. was shown on the high-pressure diagrams below the boiler pressure, which was not maintained up to point of cut-off, but fell off very considerably, showing wire drawing during admission. That should not be. He thought diagrams, shown in Figs. 39-42, taken from engines with automatic expansion gear were very much superior to any shown in the paper. In these diagrams the initial pressure was not more than from 1lb. to 1½lbs. below the boiler pressure line, and maintained the pressure practically up to point of cut-off, and fulfilled the conditions in every respect as laid down by Mr. Harper in the paper. These were taken from engines fitted with Messrs. Musgraves' automatic Corliss gear, which he was surprised to see was not mentioned in the paper, for he considered this gear second to none in the market.

He was of opinion that one of the points mostly overlooked by the makers of engines was in not making the steam pipes and passages of sufficient size to allow steam to enter and escape freely from the cylinders, and this accounted for the fact that a many automatic expansion gear engines were found working where the difference between the initial pressure in the cylinder and the boiler pressure was 5, 10, and even 15lbs. That entailed considerable loss, and such examples could be furnished in dozens, but it ought not to be the case.

With respect to Messrs. Hick, Hargreaves & Co.'s gear being arranged to have steam valve full open at one tenth of the stroke, he did not think it was of any account, nor would it be even if the valves were wide open at the commencement, when the steam pipes and passages were too small.

Mr. Harper referred to the fact of Knowles' supplementary governor being applied to engines made by Messrs. Hick, Hargreaves & Co., and the results it gave as borne out by Moscrop's recorder; but he, Mr. Hartley, asked was it not a

surprising fact that the above-named firm could not make an engine to give satisfactory results without such an addition, whilst all other makers obtained exactly the same results with only one governor? As to Moscrop's recorder he placed no reliance upon it at all, as it was liable to be and in fact was tampered with regularly. Any machine that allowed of such work he thought could not be considered reliable, and anyone who depended entirely on a Moscrop's recorder was labouring under a delusion. To his mind the best recorder in a spinning mill was the spinner himself, who never forgot to complain of any unsteadiness in the turning. In his opinion Moscrop's recorder was good for nothing except to carry about from place to place and from works to works for comparison only, it being the same one and always working under the same conditions and speed, etc.

He was sorry Mr. Harper had not shown them more diagrams illustrating the other expansion gears shown by him, as it is only by seeing the diagrams produced that an opinion can be formed of them. As to the expansion gears with a block sliding inside of a link, he considered that the Corliss expansion gears were superior to them.

He considered it absolutely necessary that all engines put down to drive dynamos should be of first-class design and make, and be fitted with automatic expansion gear of a type that gives but little work for the governor to do, if steady and reliable turning is desired combined with economy.

He thanked Mr. Harper personally for his paper, as it was one that must have cost him a considerable amount of time and trouble to write and prepare the drawings, which were a credit to him, and it would no doubt prove a valuable addition to the records of the Association.

Mr. Ingham drew attention to the necessity in every case of there being a certain amount of lap on the main slide valve.

He entirely agreed with the remarks of Mr. Goodfellow when he emphasised the necessity of the separation of the duty of the boiler from that of the engine. He cited a case at a mill with two engines, one of which was working with 3lbs. and the other with 2½lbs. of coal per horse-power per hour, and yet the former

was the cheaper of the two ; the reason being that in the first instance the boiler was fired with poor coal, and in the second case the fuel was of good quality at a higher price.

The great objection to the use of the Cornish valves, in his opinion, was the loss in clearance space as compared with the Corliss valves.

Mr. Hartley's remarks, he thought, were more directed to mill engines than to the engines to which automatic expansion gear was especially applicable.

The President said it appeared to him that the discussion had turned principally on large stationary engines in connection with mills. The last speaker had alluded to the advantage in adopting automatic expansion gear with varying loads, and in regard to this he had recently had a remarkable illustration. He saw an engine to which seven or eight stoking machines were attached, and although two, four, and sometimes eight machines were working, there was little variation in the speed of the engine. The automatic expansion gear in that instance was a great advantage. It appeared to him that the necessity of adopting automatic expansion gear all depended upon the variability or reverse of the load on the engine. When there was a steady even load on the engine with the throttle valve wide open, he did not think much advantage was got by using it.

He certainly did think that they ought to be more scientific in their investigations, and to insist on a steam engine being judged on its consumption of steam, as one might be led astray by merely considering the pounds of coal used. Then again the coal might contain a more or less quantity of ash, in different instances.

He should like Mr. Harper to say whether automatic expansion gear would be equally as advantageous on small engines as on large stationary engines.

Mr. Harper in replying, thanked the members for the attention accorded to his paper. He might say that he did not advocate automatic expansion gear in every case, say in blowing engines, pumping engines, and all engines with a constant load, when he thought much advantage would not

be gained by adopting it. But take the rolling mill engine, engines for driving cement mills, or even machine tools, where there were great variations in the load, in those cases he thought the adoption of the throttle valve would be productive of loss, compared with the automatic expansion gear.

He agreed with Mr. Goodfellow in the remarks respecting the steam passing through the exhaust ports. Of course there would be a cooling effect on the valves, but he might point out that Wood's engine gave good results, and likewise the Wheelock engine.

He coincided with the observations made, regarding having too little compression. He had seen cases where the beating of the crank pin had been entirely obviated by putting more compression on. Regarding small engines he had not had much experience in the application of automatic expansion gear to them, but from reading of the results of Dr. Proell in that direction he found that gentleman obtained an economy of steam consumption of ten per cent., and in some cases of thirty per cent.

On the motion of the PRESIDENT, seconded by Mr. J. WALTHEW, a vote of thanks was passed by acclamation to Mr. Harper for his interesting paper.

DIAGRAMS.

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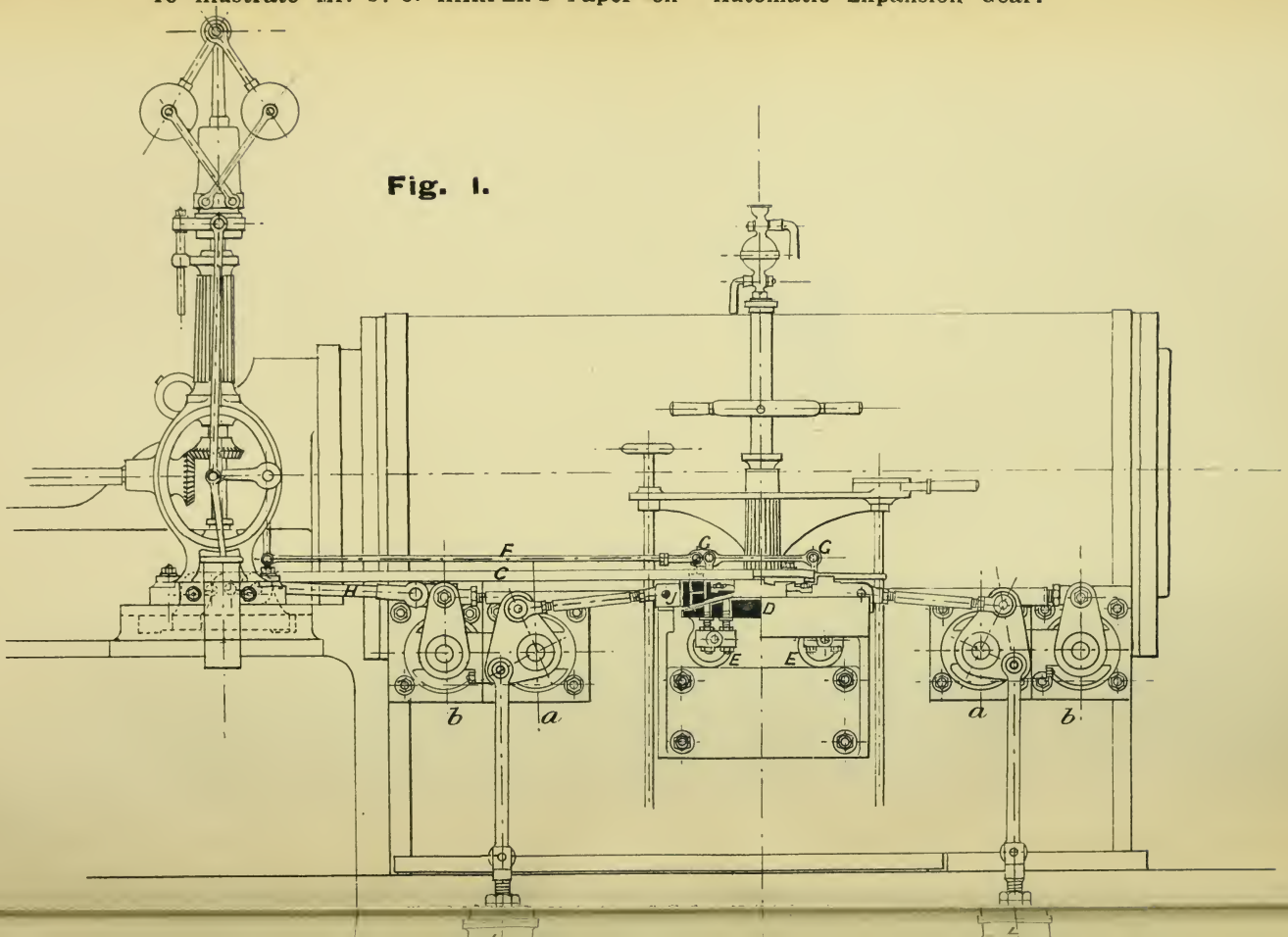
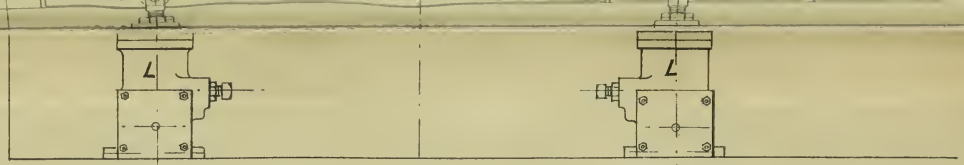
To illustrate Mr. J. J. HARPER'S Paper on "Automatic Expansion Gear."

Fig. 1.





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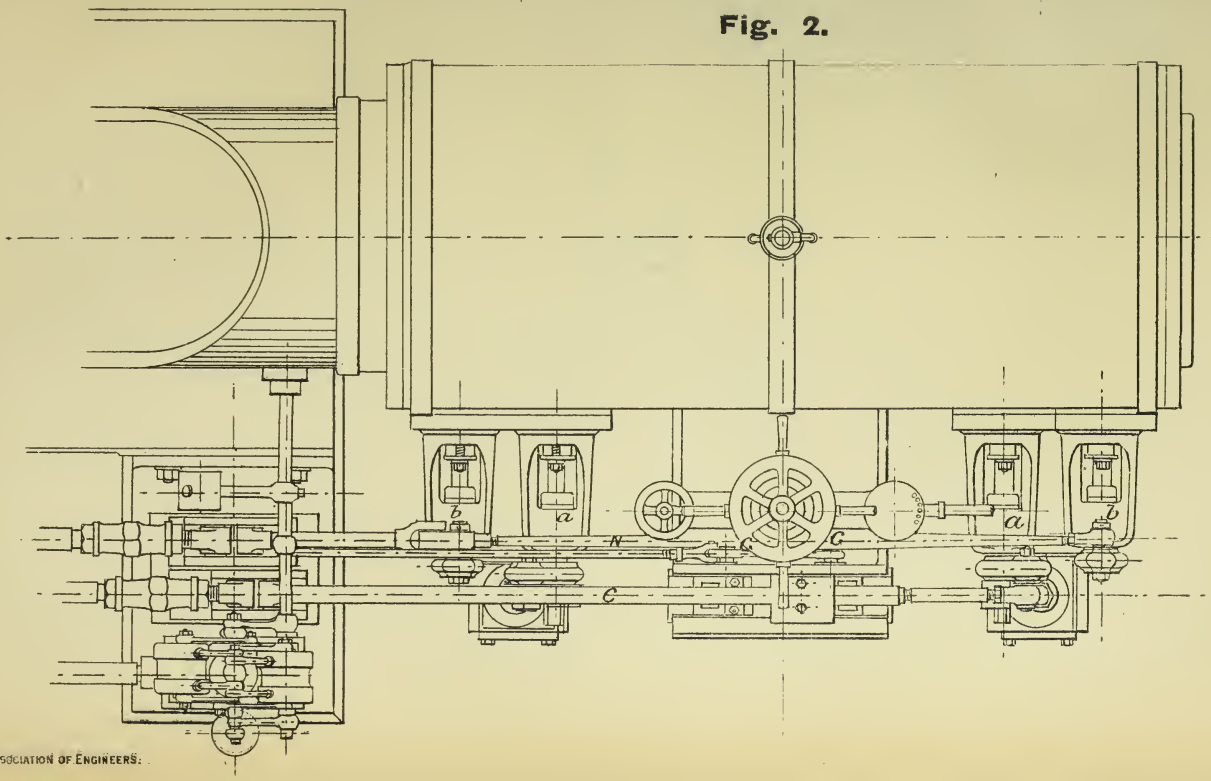

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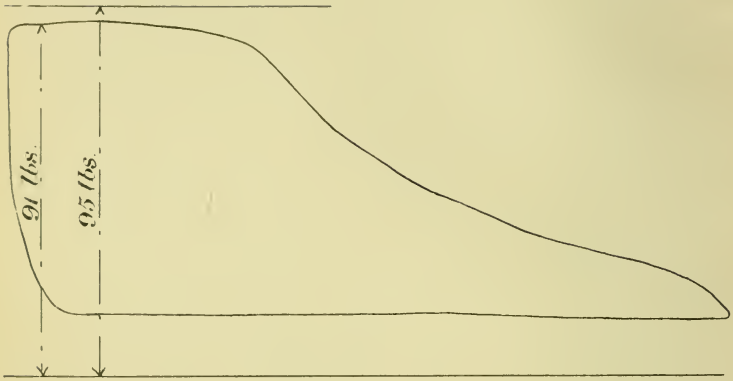

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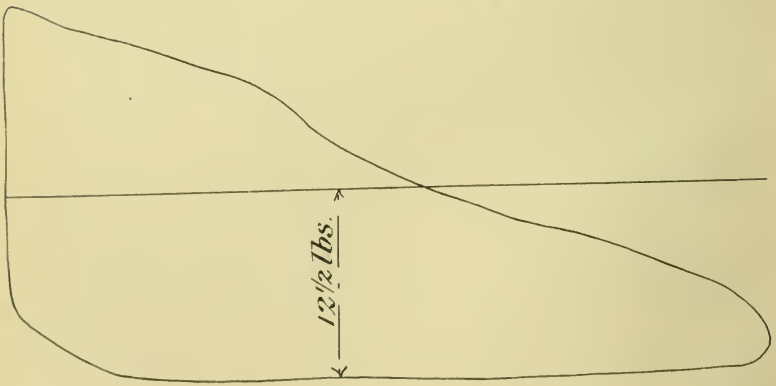

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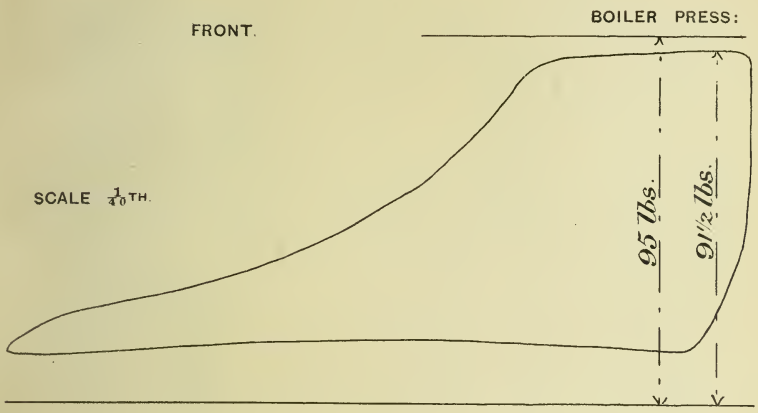

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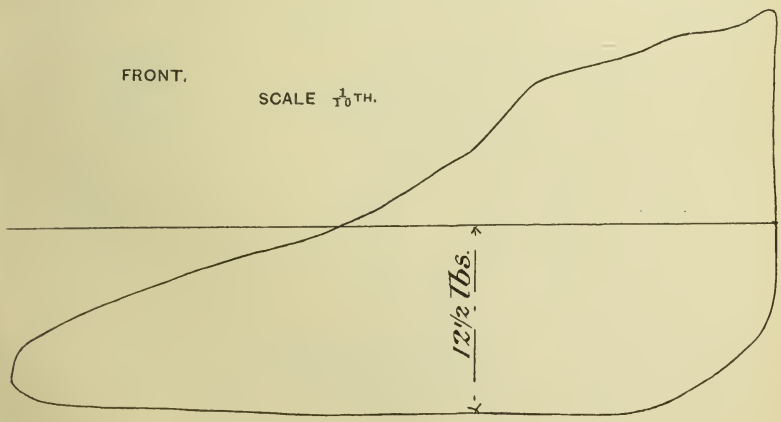

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To illustrate Mr. J. J. HARPER'S Paper on "Automatic Expansion Gear."

Fig. 3.

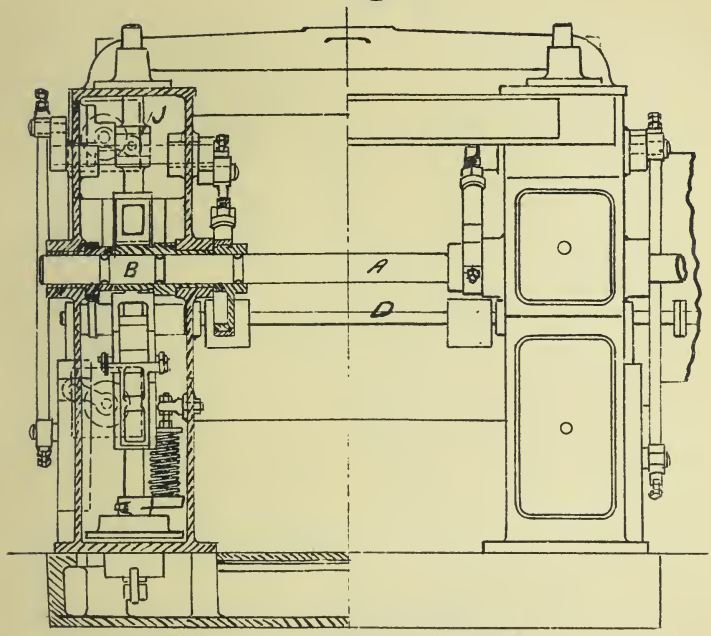

Fig. 4.

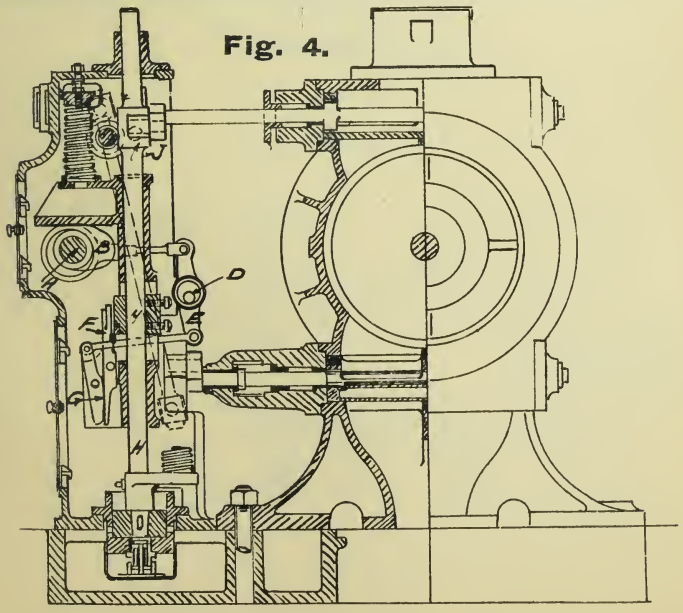

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Fig. 5.

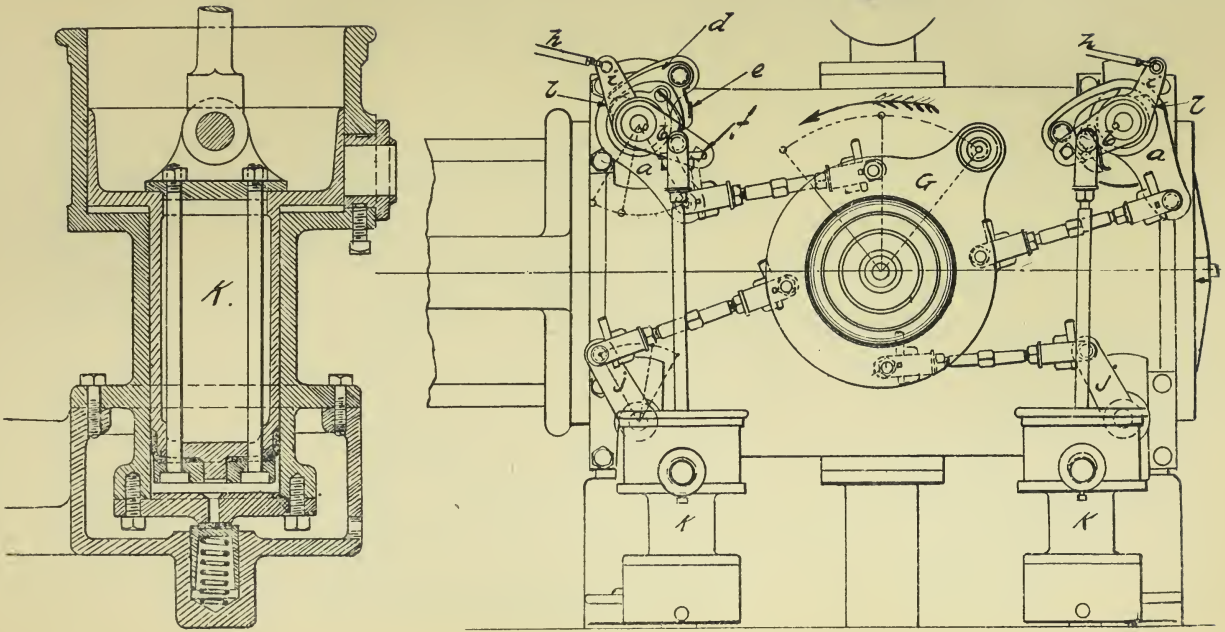

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Fig. 6.

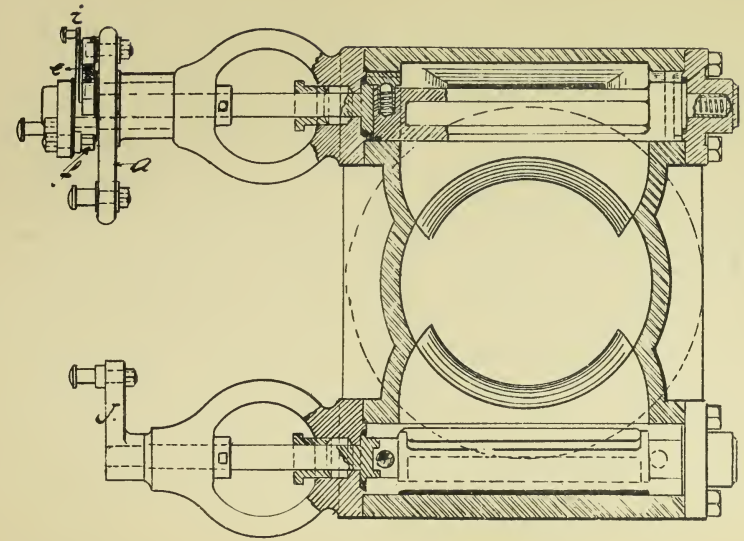
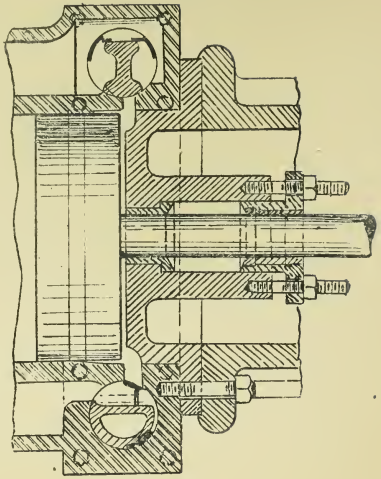
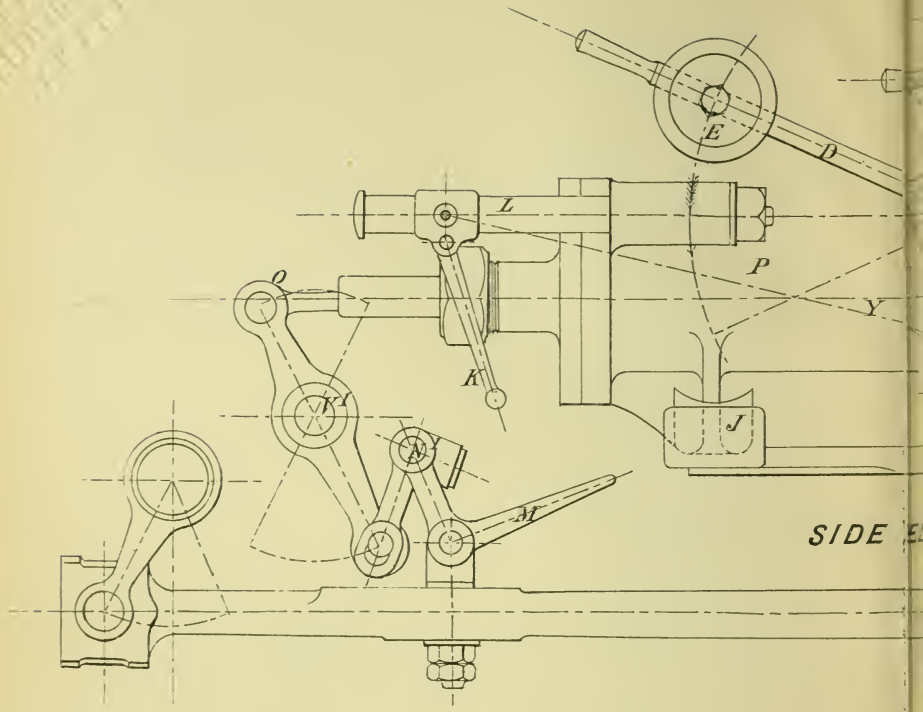


Fig. 6a.

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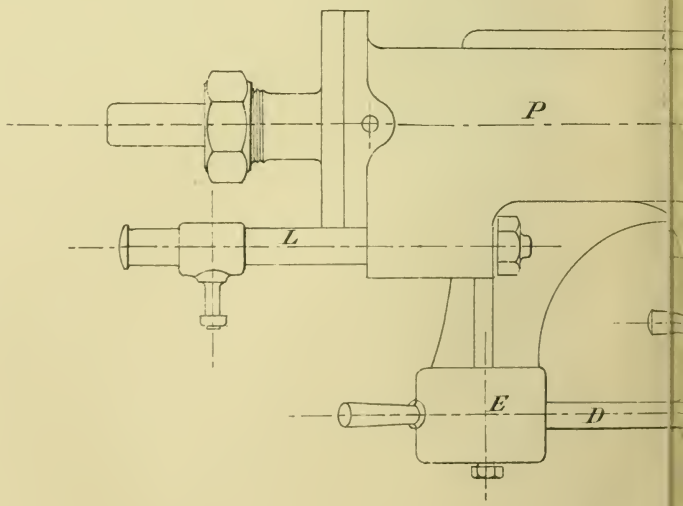
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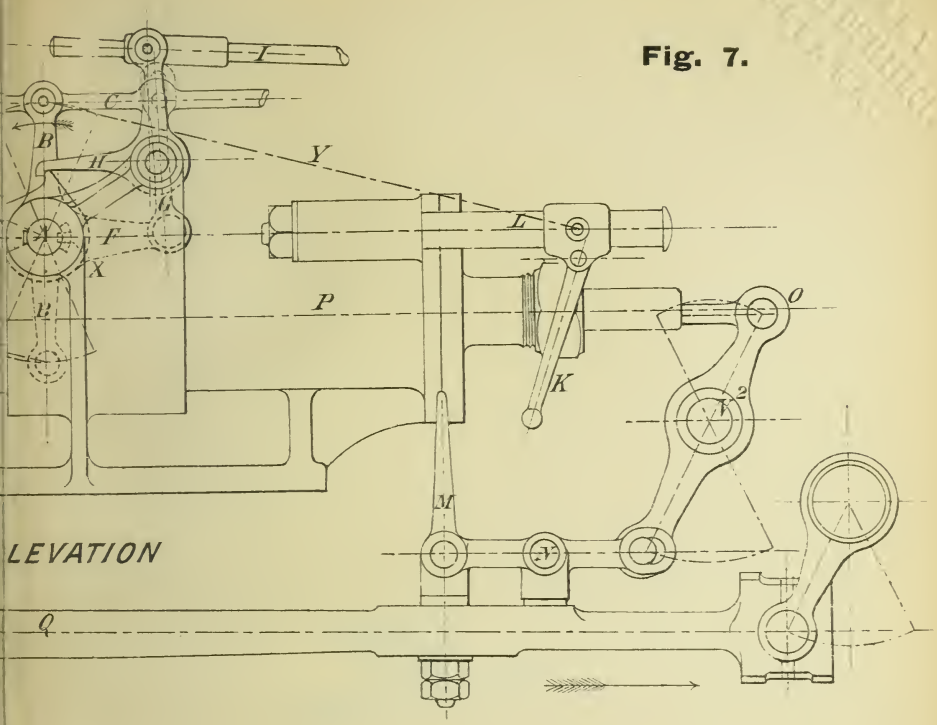
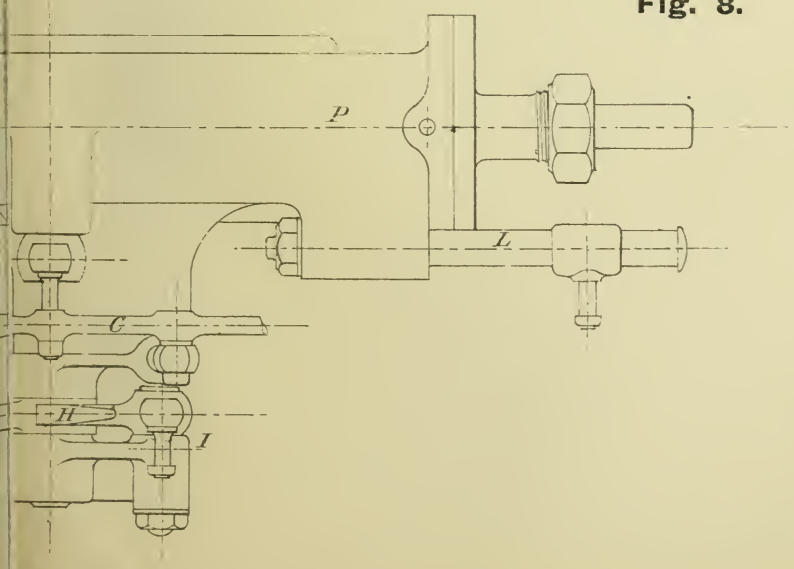


Fig. 8.



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To illustrate Mr. J. J. HARPER'S P

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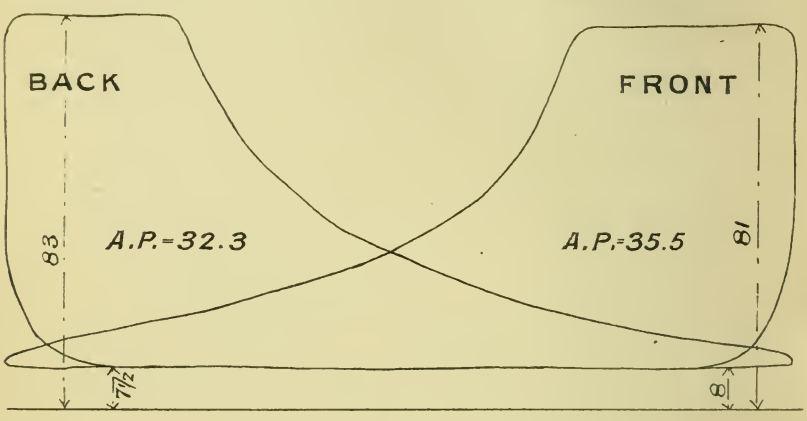
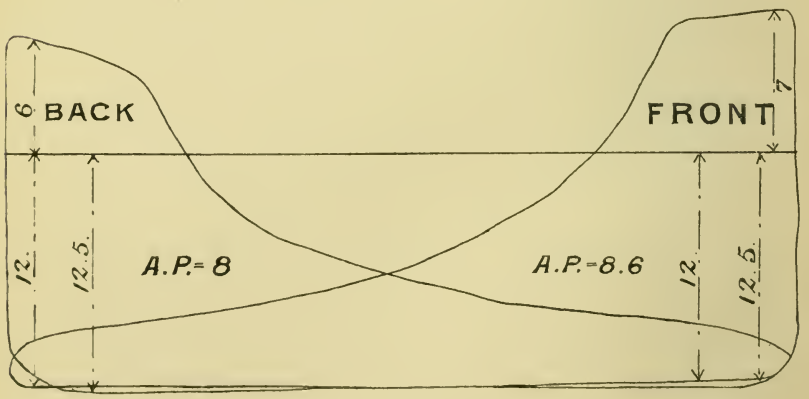
Indicated horse-power 915.9 Coal

LEFT HAND ENGINE.

Boiler Pressure 85 lbs.





Paper on "Automatic Expansion Gear."

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connection with Figs. 7 and 8.

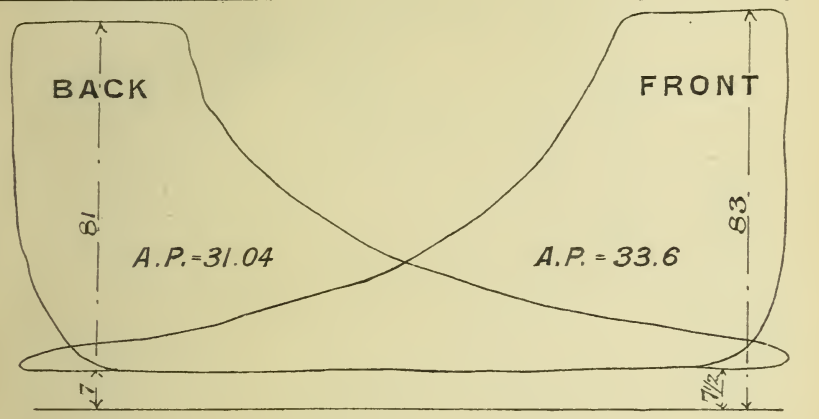
in June, 1884.

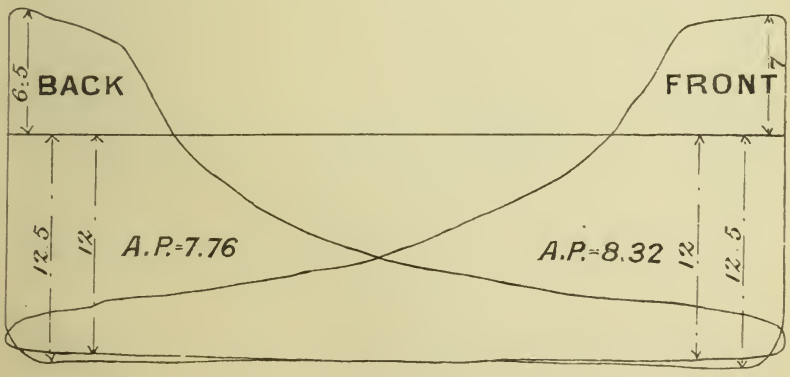
ine made by Mr. B. Goodfellow, Hyde, for Mr. John Mayall, Mossley.

consumed per horse-power per hour 1.69 lbs.

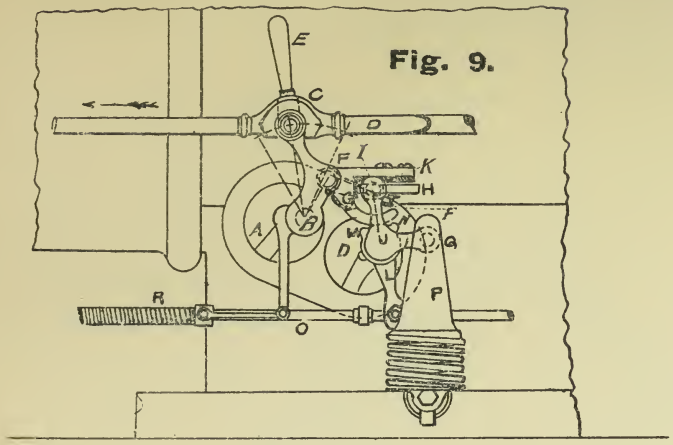
RIGHT HAND ENGINE

Boiler Pressure 85 lbs.





To illustrate Mr. J. J. HARPER'S Paper on "Automatic Expansion Gear."



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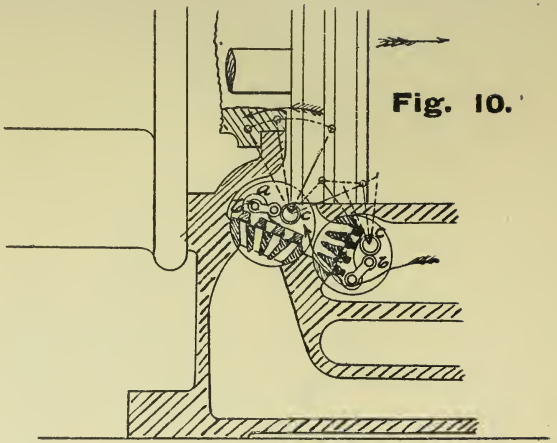

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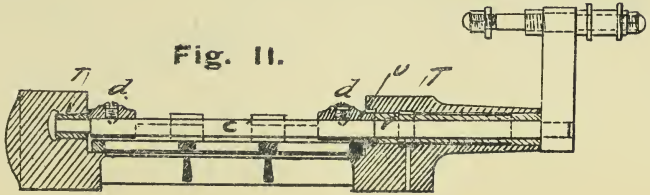

Fig. 11.

To illustrate Mr. J. J. HARPER'S Paper on "Automatic Expansion Gear."

Fig. 12.

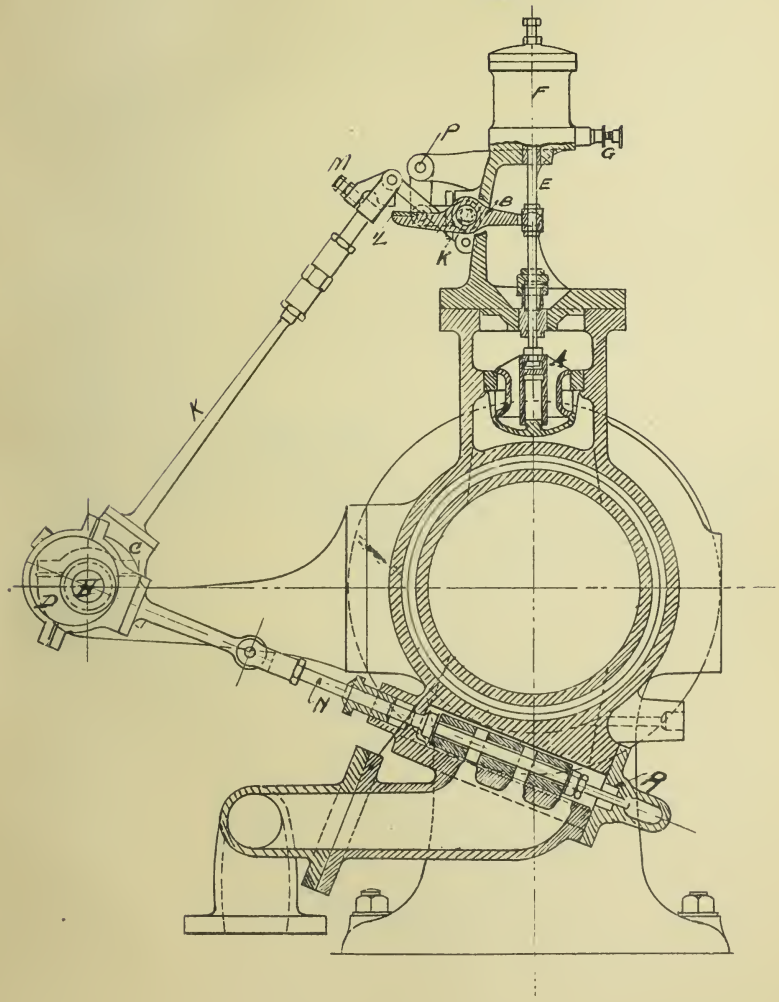

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Fig. 13.

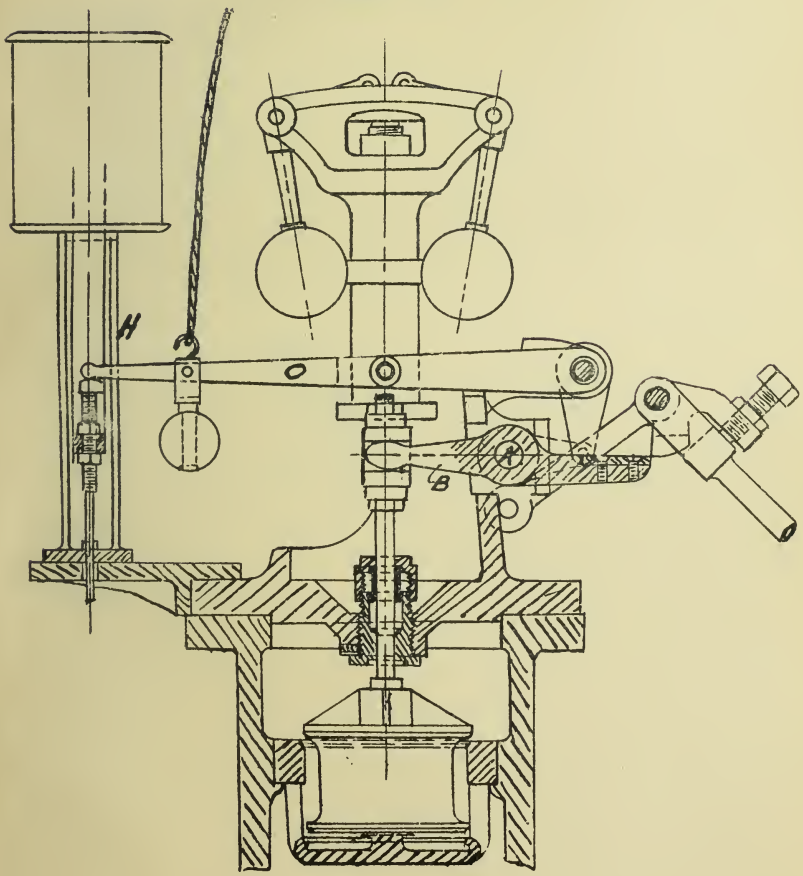

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Fig. 14.

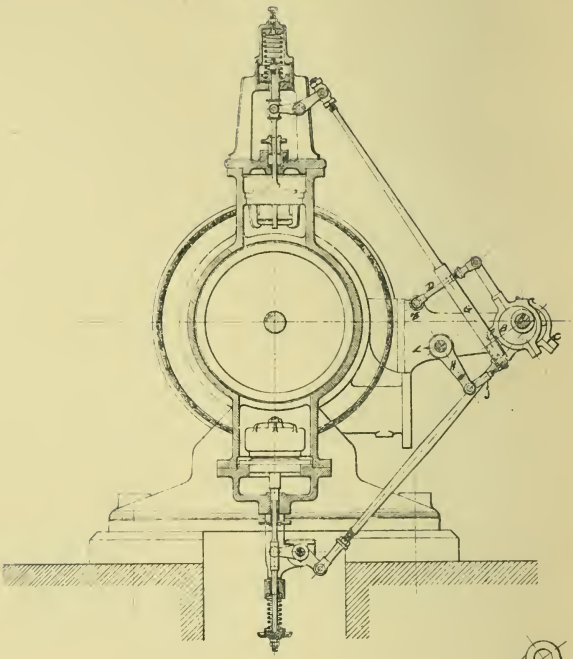
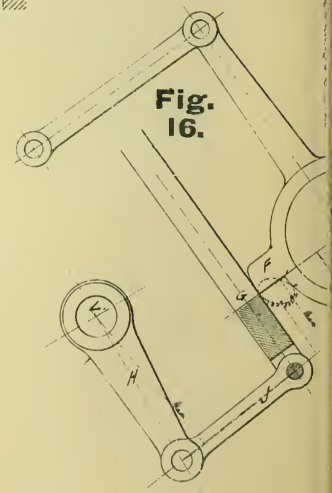


Fig. 16.



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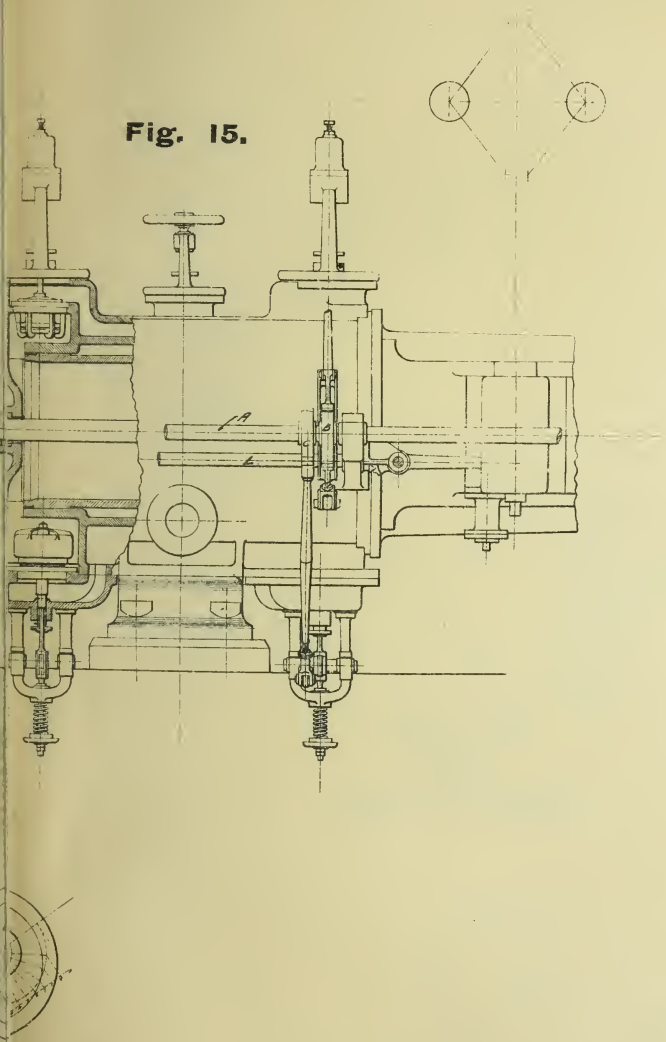

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To Illustrate Mr. J. J. HARPER'S Paper on "Automatic Expansion Gear."

Fig. 17.

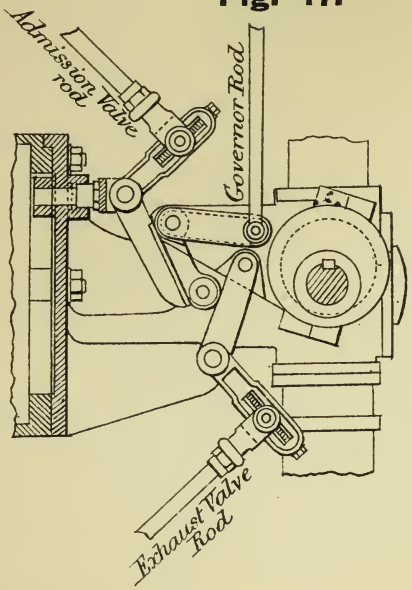

Fig. 18.

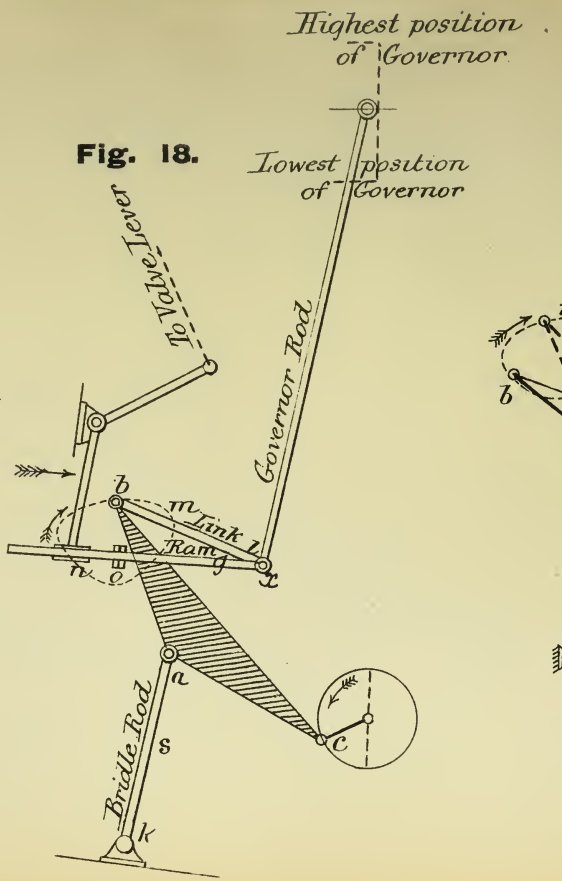

Fig. 19.

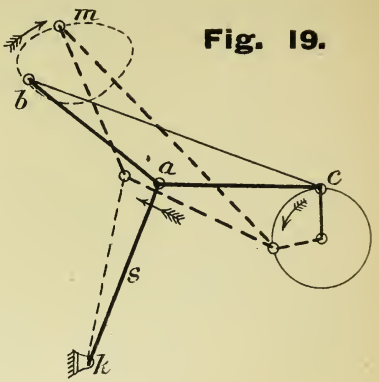

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Fig. 20.

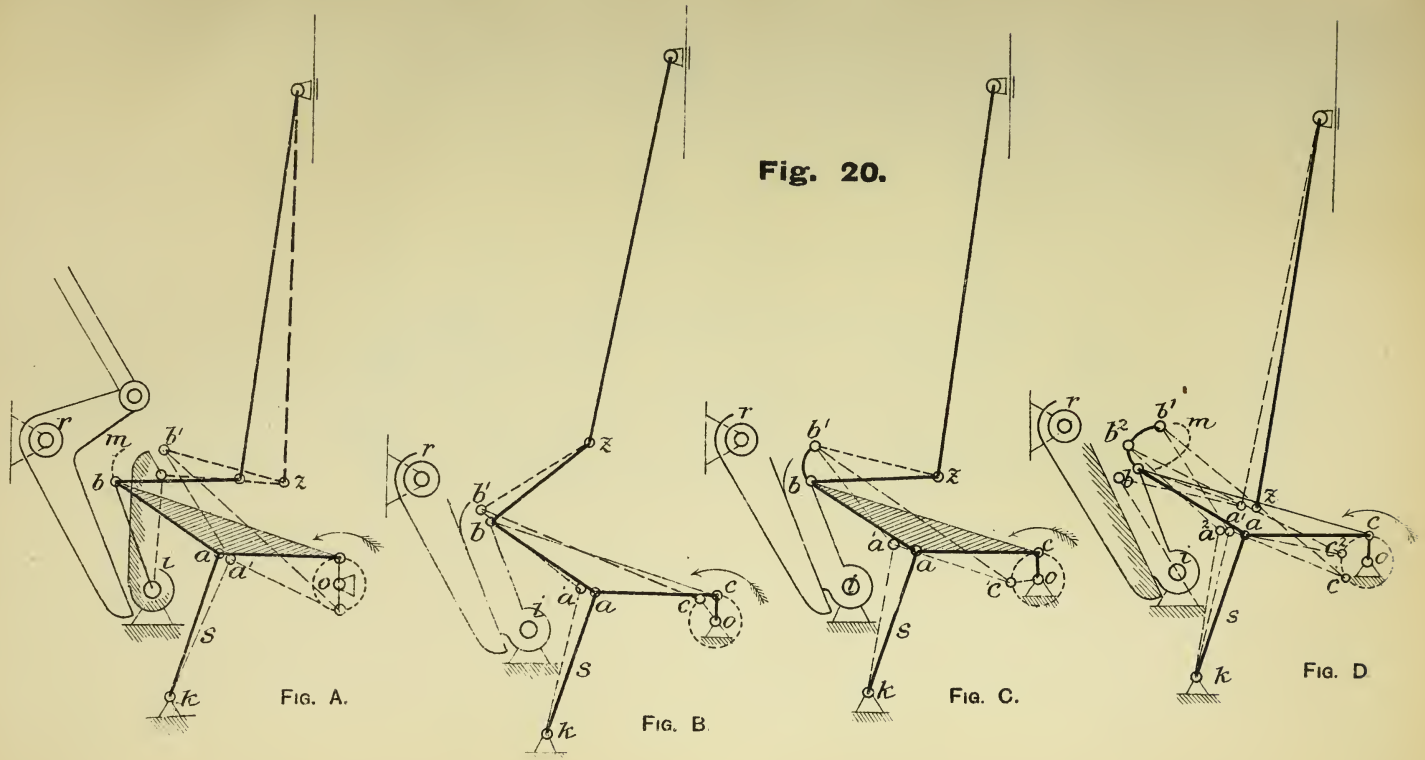

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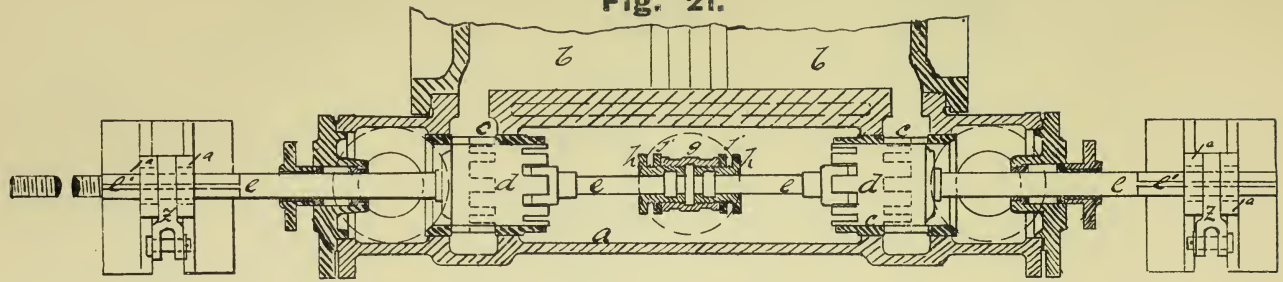
Fig. 21.



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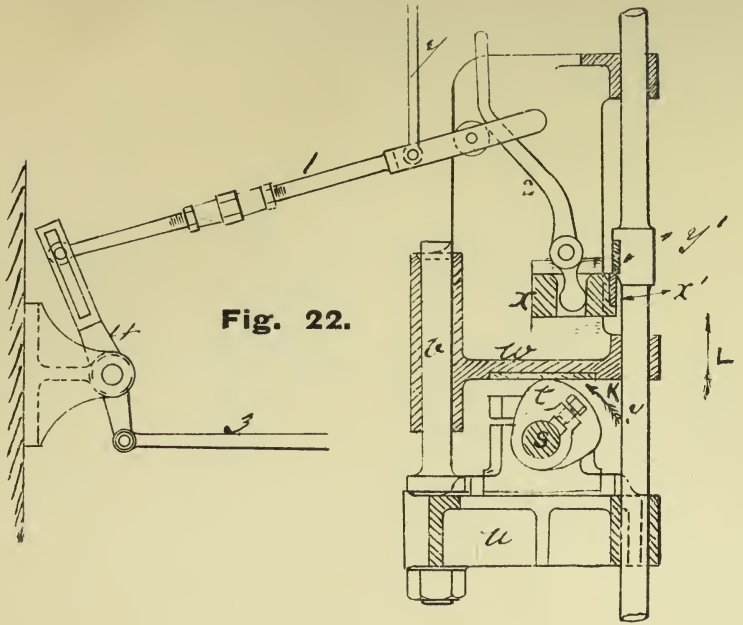

Fig. 22.

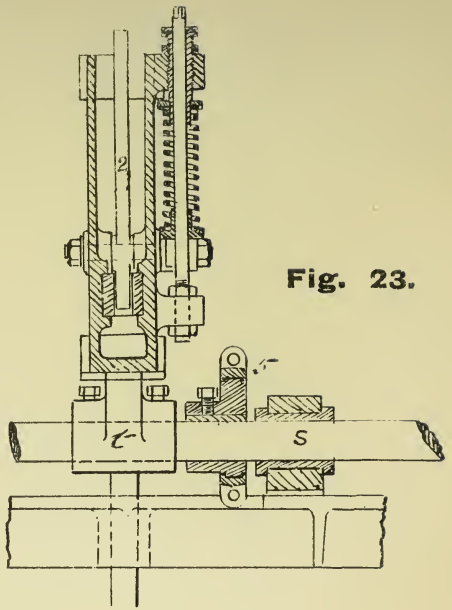

Fig. 23.

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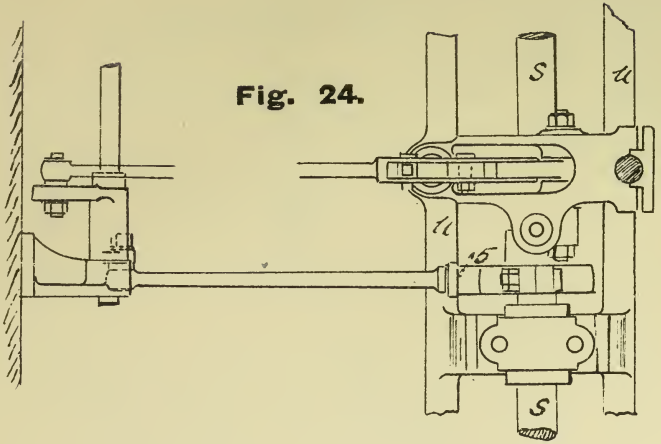

Fig. 24.

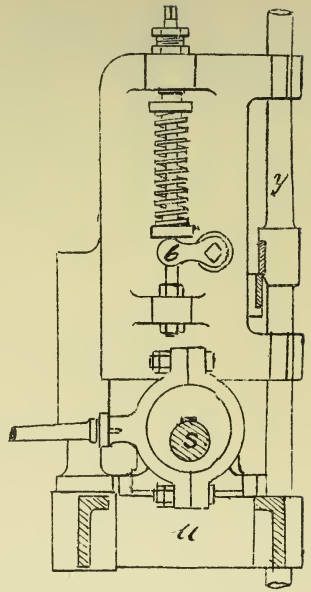

Fig. 25.

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Fig. 26.

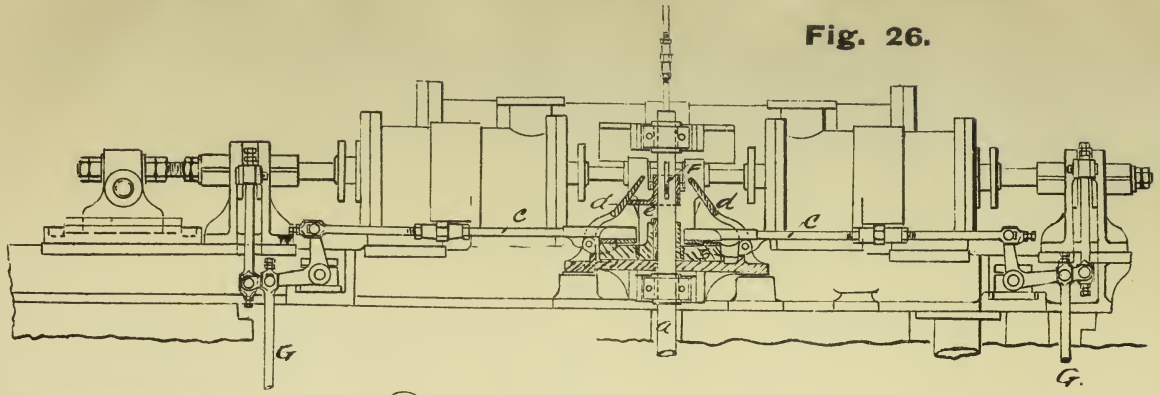
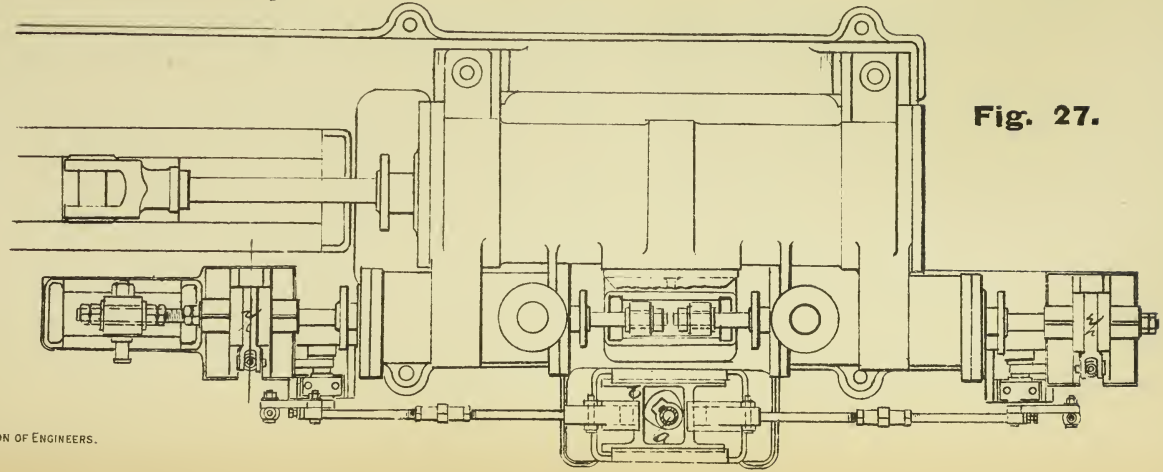
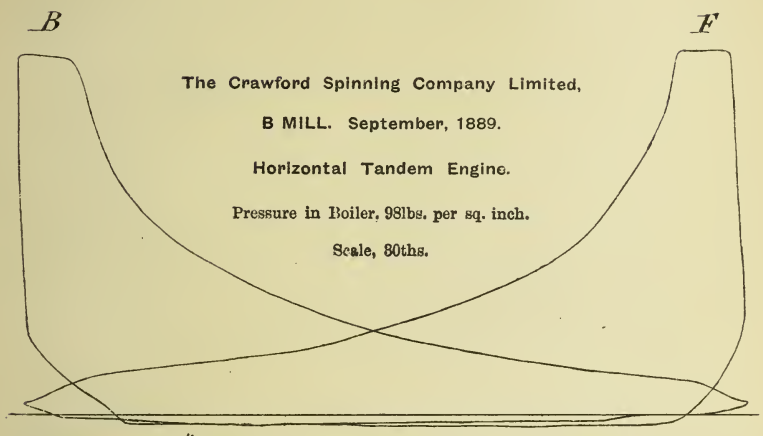


Fig. 27.

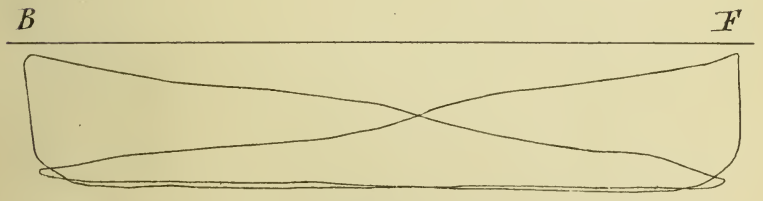


To illustrate Mr. J. J. HARPER'S Paper on "Automatic Expansion Gear."

Indicator Diagrams in connection with Figs. 26 and 27



Cylinder 15" dia. *Stroke 3'. 0"* *Revs. 70 per min.*



Cylinder 28" dia. *Stroke 3'. 0* *Revs. 70 per min.*

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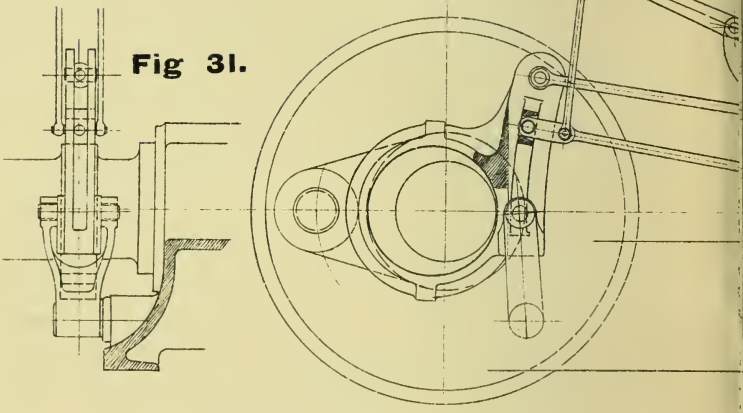
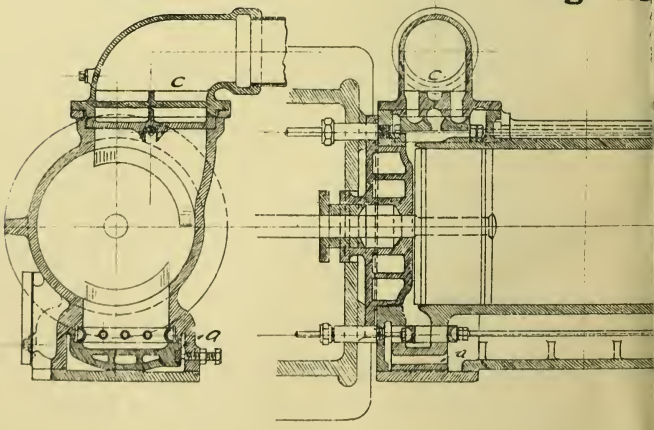


Fig 31.

Fig. 30.

Fig. 29



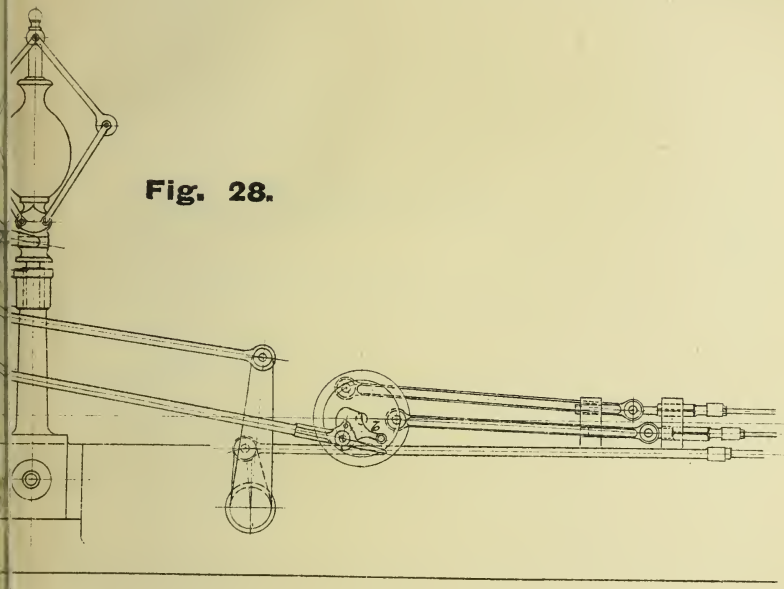
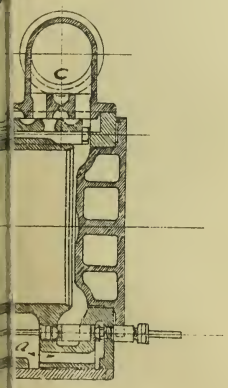


Fig. 28.



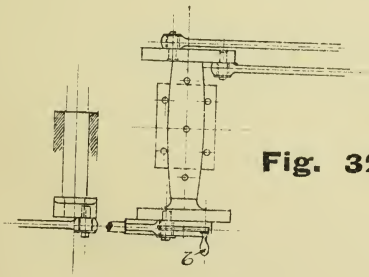


Fig. 32.

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To illustrate Mr. HARTLEY'S remarks in Discussion on "Automatic Expansion Gear."

Indicator Diagrams from Throttle Valve Engine with lapped slides.

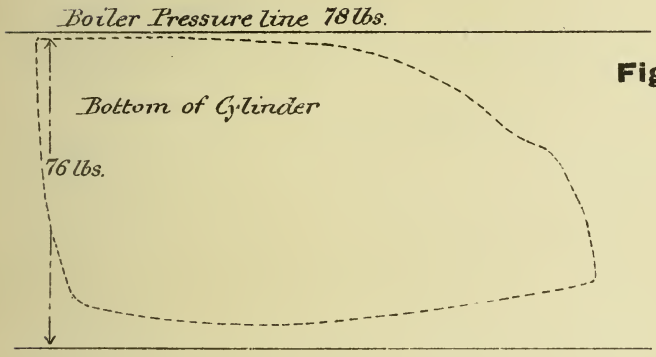

Fig. 33.

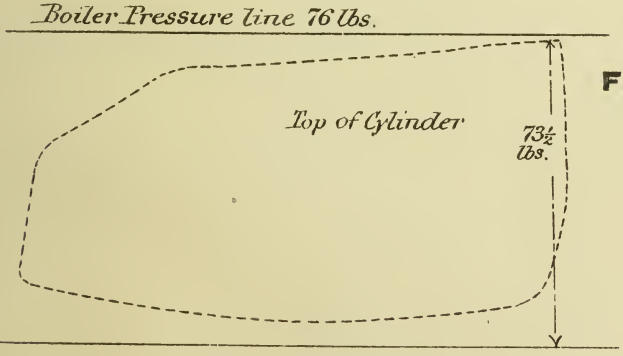

Fig. 34.

To illustrate Mr. HARTLEY'S remarks in Discussion on "Automatic Expansion Gear."

Indicator Diagrams from Throttle Valve Engine with lapped slides.

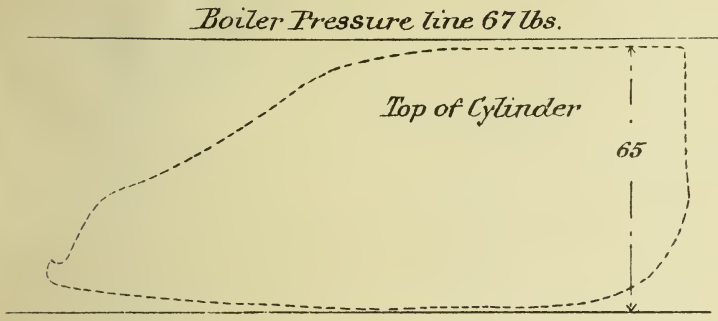

Fig. 35.

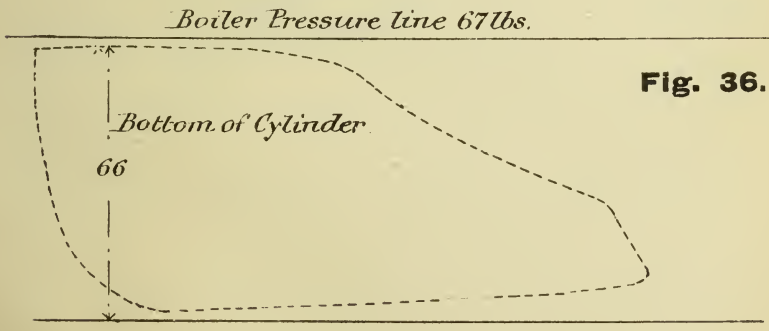

Fig. 36.

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Indicator Diagrams from Throttle Valve Engine with lapped slides.

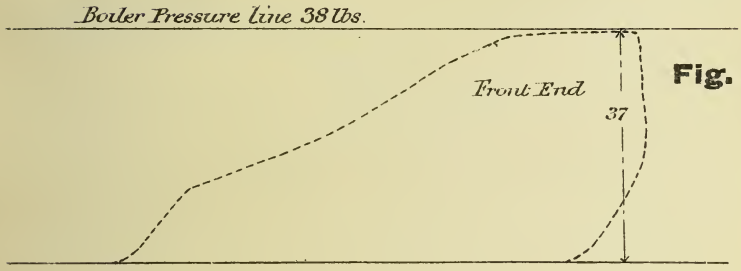

Fig. 37.

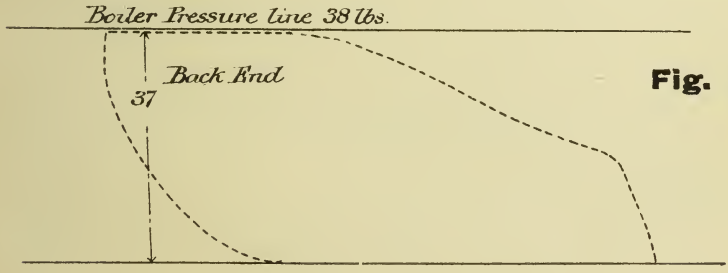

Fig. 38.

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To illustrate Mr. HARTLEY'S remarks in Discussion on "Automatic Expansion Gear."

Indicator Diagrams from Engines with Corliss Expansion Gear.

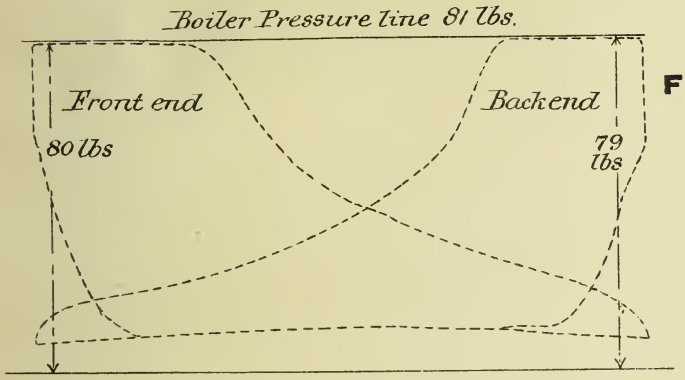


Fig. 39.

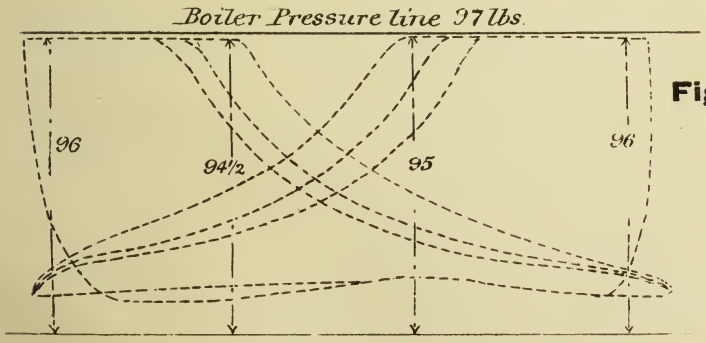


Fig. 40.

To illustrate Mr. HARTLEY'S remarks in Discussion on

"Automatic Expansion Gear."

Indicator Diagrams from Engines with Corliss Expansion Gear.

Fig. 41.

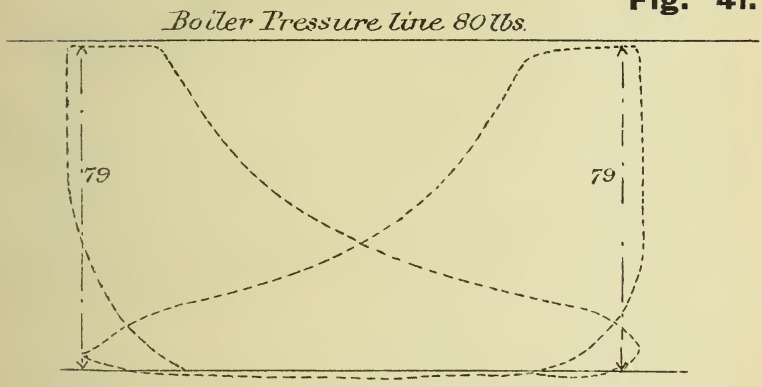
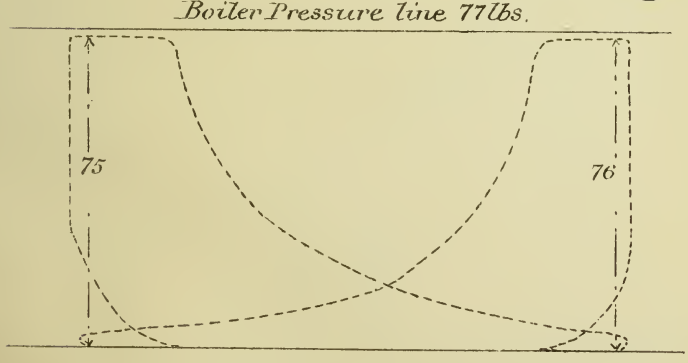


Fig. 42.



To illustrate Mr HARTLEY'S remarks in Discussion on "Automatic Expansion Gear."

Mean of a set of Indications from a Pair of Compound Tandem Engines compared with Hyperbolic Expansion Curve. Date of Indications, March 1st, 1887.

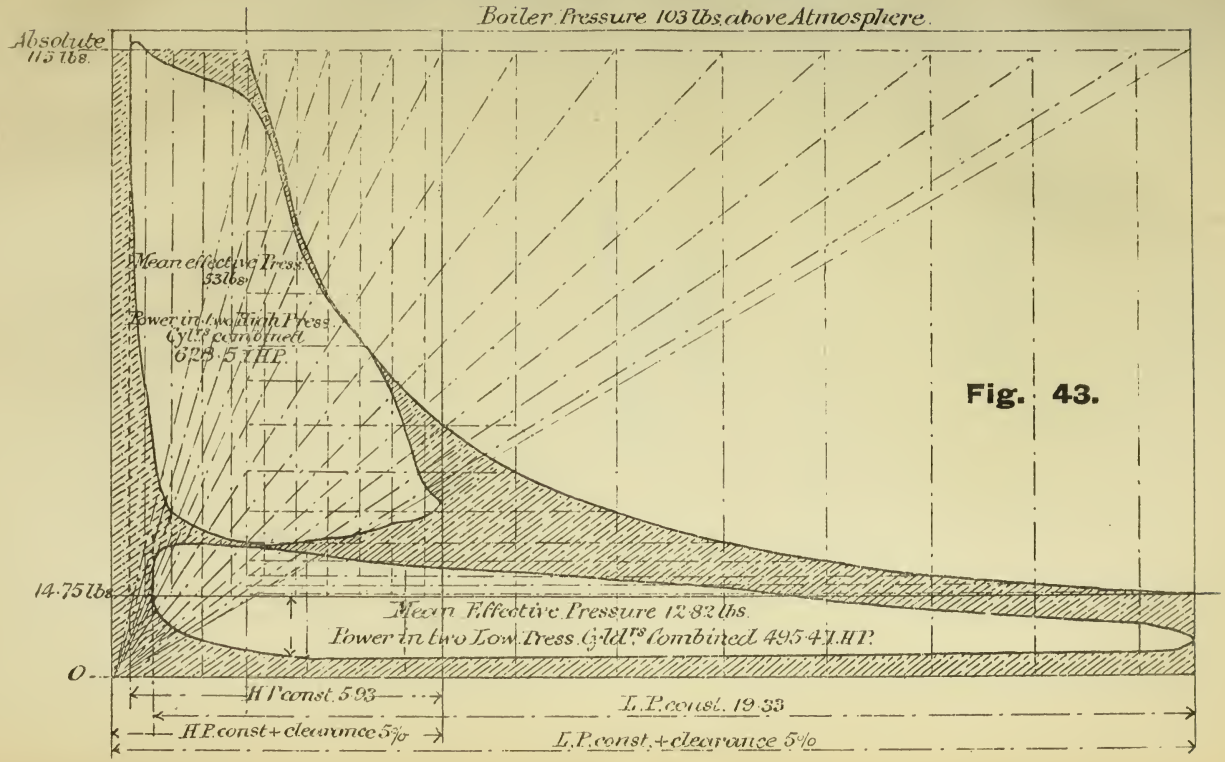

Boiler Pressure 103 lbs above Atmosphere.
Absolute 115 lbs.
Mean effective Press. 33 lbs.
Power in two High Press. Cyl.rs combined 628.5 I.H.P.
14.75 lbs.
Mean Effective Pressure 12.82 lbs.
Power in two Low Press. Cyl.rs combined 4954 I.H.P.
O.
H.P. const. 5.93
L.P. const. 19.33
H.P. const + clearance 5%
L.P. const. + clearance 5%

Fig. 43.

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STEAM CRANES.

A PAPER

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On 22nd NOVEMBER, 1890.

AT THE GRAND HOTEL, MANCHESTER,

MR. THOMAS DANIELS

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STEAM CRANES.

It is not intended to enumerate the designs of steam cranes generally, but more particularly to describe the application of compound engines as a motive power. A few details will also be described, which the writer, in his capacity as engineer to Messrs. John Freeman & Sons, the well-known owners of the Cornish granite quarries, and who, it may be mentioned in passing, are supplying a large amount of granite for the Ship Canal, has from time to time found advantageous for efficiency, reduction of first cost, and wear and tear.

Compound Engines adapted to Cranes.

The high price of fuel in Cornwall, where it costs 20/- to 25/- per ton at the quarries, determined compound engines being applied to a 20-ton crane built some years ago by the above mentioned firm.

GENERAL DESCRIPTION OF CRANE.

The crane, which is of the Derrick type, has the mast, jib and guys built of steel, on the lattice principle. Fig. 1 shows it in elevation. The jib is 46ft. long, the mast 25ft. high, supported by the guys, which are placed at an angle of 90° and run at an angle of 45° to the horizon. The weight, complete with boiler, engines and gearing, is $15\frac{1}{2}$ tons.

The hoisting gear consists of a winding drum or barrel 2ft. diameter, for the reception of the lifting wire rope, and it is mounted on a shaft which also carries a spur wheel with 76 teeth. On the intermediate shaft is keyed a pinion with 11 and a wheel with 58 teeth; the pinion gears into the barrel shaft spur wheel, while a pinion with 14 teeth, mounted on the crank shaft, can engage with the wheel.

This constitutes the full or double power, and is a purchase of 28·6 to 1.

Another pinion on the crankshaft, with 11 teeth, can gear directly into the large spur wheel on the barrel shaft, and constitutes the single power used for light loads.

The crane is designed to lift 7 tons with the single, 13 tons with the double, and 20 tons with the treble rope. For the two latter purchases a snatch block is provided, which requires only a few minutes to attach, as the wire rope 3½in. circumference is easily handled.

LIFTING SPEEDS.

With the engine shaft running at 150 revolutions per minute and taking the average diameter of the barrel with rope on it at 2ft. 6in., the lifting speeds are as follows:—

Single power,	163ft. per min.	Weight lifted,	2 tons.
Full power,	40ft. ,,	,,	7 ,,
Double rope purchase,	20ft. ,,	,,	13 ,,
Treble rope purchase,	13ft ,,	,,	20 ,,

As the speed of lifting is considerable, especially for the heavier weights, the engines must be capable of being quickly and easily handled.

DESCRIPTION OF ENGINES AND BOILER.

The compound engines have a high-pressure cylinder 7½in. diameter, and a low-pressure cylinder 12in. diameter, both with 12in. stroke; the cranks are at right angles, and a receiver equal in capacity to the cubical contents of the high-pressure cylinder is provided.

The engines are designed for a steam pressure of 120lbs. per square inch.

The slide valves are worked by link motions, the steam being cut off at a little over ⅞ stroke in each cylinder. For readily starting from positions in which no steam is admitted to the high-pressure cylinder, or for overcoming the inertia in starting with a heavy load, a ¼in. pipe conveying live steam is led into the receiver, the admission being controlled by a valve arranged to work by the driver's foot pressing a button. The engines are as easily handled as simple ones, and are found handy when starting with a heavy load on.

The boiler is of the vertical type, 7ft. high × 2ft. 9in. diameter, the fire-box being 4ft. high × 2ft. 3in. diameter, with two cross water tubes 7in. diameter, and it is found capable of raising ample steam.

COST.

The extra cost of the compound engines is more than balanced by the reduced cost of the boiler, as it is smaller than if simple engines were used (the only difference between the two engines being the larger diameter of the low pressure cylinder), while the repair cost is found to be no more.

ECONOMY OF FUEL.

This crane has been in constant use for four years; the economy in fuel is most marked, being about half that used for a crane doing exactly similar work but fitted with simple engines having cylinders 7in. diameter × 10in. stroke, and 60lbs. per square inch steam pressure. These latter engines were thoroughly overhauled shortly after the compounds were built. As is usual in crane and winch work the simple engines carry steam about $\frac{7}{8}$ of the stroke.

The writer is of opinion, judging from the satisfactory result of this application, that compound engines might with advantage be applied to steam cranes, winches, &c., with a marked reduction in fuel and water consumption, two very important factors.

India Rubber Buffers applied to the end of the Lifting Ropes.

The application of a spring arrangement to the end of the lifting ropes to act as a cushion to the whole structure, is of great value in lessening the shock when a weight is lifted or released. They are precisely like the draw bar springs of a railway waggon, and quite as essential and effective in relation to cranes. The rubbers are found to last a long time, being well protected by the wrought-iron plates which also enable the buffers to expand freely.

Figure 2 is a drawing of a set arranged for a 10 ton crane, and clearly shows the arrangement without further description.

Flying Jib applied to Heavy Cranes for lifting Light Loads.

It being found necessary to deliver waste granite about 60ft. above the level of the platform on which the heavy compound crane just described is standing, it was decided to utilize this crane and a flying jib was erected on the end of the jib proper.

The arrangement is shown on Fig. 1, and it is designed to lift 3 tons.

The combined length of the jibs is 80ft. A separate lifting rope and barrel is provided, worked however by the same engines.

Such an arrangement might be useful in many circumstances especially in utilizing heavy cranes for light work, advantage being taken of the great strength, comparatively speaking, of the crane proper to enable light loads to be handled at a considerable radius.

Steel Wire Lifting Ropes.

At the above mentioned quarries wire ropes have been used instead of chains for the last seven years.

Taking all things into consideration they are much cheaper. Owing to their smooth working, severe shocks, as for instance when a chain "rides," are avoided. They are lighter, and therefore easier to handle, especially for quarry work where they often have to be carried some distance; they also give timely warning of any weakness and are thus safer to work under. During the seven years in which they have been in use, not one case has been recorded of the weight falling due to breakage of the rope.

The pulleys and barrel round which a wire rope works should be made large in diameter, but there is a limit to such in the case of cranes where a large barrel means correspondingly large gearing to get the necessary power. It is found that a 2ft. diameter pulley or barrel answers well for a 3½in. circumference rope. The jib head pulley, however, should be made as large as possible, as a rope generally fails first at the part which passes over this pulley when the weight to be lifted is being taken.

The wires comprising the rope should be small, the best results being got from ropes made out of Patent Plough Steel wire with hemp core, six strands to the rope, and each strand consisting of 19 wires. They should be well lubricated with a mixture of oil and tar. Such a rope has lasted four years doing heavy and continuous work, often strained to over 1-7th of its ultimate strength.

Arrangement of Lifting Barrel.

The speed of lifting is an important matter, but equally so is the speed of lowering.

The ordinary method of keying the lifting barrel to a shaft on which is again keyed a spur wheel into which the pinion on the intermediate shaft works (this shaft carrying the brake wheel), entails the revolution of this train of gearing when lowering, and the speed suffers in consequence.

If the lifting barrel, with the brake wheel attached, is arranged to run loose on its shaft, the lowering speed is enormously increased, being in fact nearly equal to that of a falling body. A strong clutch gear puts the barrel in gear with its shaft.

In this arrangement a good brake is essential, and there is no difficulty in designing a foot brake for loads of from 3 to 4 tons the brake wheel being twice the diameter of the wire rope barrel. For heavier weights a small steam cylinder is applied to the end of the brake gear lever, in a manner similar to the steam brake of locomotives.

None of the foregoing details are claimed as novelties, but I am not aware of their systematic use, and there is little doubt that the application of them to other than quarry practice may be found equally advantageous.

DISCUSSION.

Mr. Settle was of opinion that the intermittent working of the cranes was against the adoption of compound engines, and unless a considerable boiler pressure were carried, he did not think much economy would accrue therefrom. The pressure of 120lbs. was rather high for the small boiler referred to in the paper, and under the circumstances under which it was worked would certainly require careful manipulation. With regard to the buffer arrangement, he thought something of that kind was done in all forge cranes, though in some cases a helical spring was used.

Mr. Mannock said he had always been a strong advocate of compound engines, where it was likely that some economy might be obtained by their adoption, but he must confess that in the case before them he could not see how such was to accrue, when it was remembered that the engines only ran for a minute or two at a time. The great thing in the compound engine was the reduction of the range of temperature in the cylinders, which could not be got in their application to steam cranes for the simple reason that it was necessary to carry the steam considerably past the half stroke. Therefore, the steam being kept on there was no great range of temperature in the cylinders, the steam on being exhausted in the receiver being of not much lower pressure than when it was cut off. To his mind it was not apparent why compound engines should be used at all under the circumstances referred to, though probably the price of fuel may render them more advantageous. He did not like small boilers, because they required more attention and care, on the part of the driver, than a large one with plenty of water capacity, which he thought was the best. Referring to the diameter of the pulley for wire ropes, he said his experience was that the diameter of the pulley was not connected directly with the diameter of the rope, but rather with the wires comprising the rope. Mr. Donald pointed out, that for a 3½in. rope a 24in. pulley was sufficient, but in his opinion that depended on the diameter

of the wires, and not at all on the diameter of the rope. He could not coincide with Mr. Settle in his contention that 120lbs was a high pressure for a little boiler, because it produced no higher stress than a 6ft. 6in. boiler working at 60lbs. He believed that high pressure boilers were equally as safe, and gave as little trouble as low pressure boilers.

Mr. Samuel Boswell said it appeared to him that Mr. Donald came from a well regulated quarry, because he believed if there was one class of boiler which required restricting in pressure more than another, it was the vertical boiler at stone quarries. Even at some quarries, where they were supposed to have a chief engineer, he found that great carelessness prevailed so that if the compound system necessitated high pressure boilers, it was requisite that there should be competent persons to deal with them. He might add that 75 per cent of the boilers for steam cranes were left uncovered and unclothed, and perfectly open to the atmosphere, therefore, it was useless to adopt the compound principle to save either steam or fuel, if no attempt was made to keep the boiler warm, and thus obviate the radiation which took place.

Mr. E. G. Constantine, alluding to the remarks on the intermittent working of steam cranes, admitted that to a certain extent they were true, but on the other hand there were steam cranes and steam winches, which, when once started, were constantly kept at work, say for instance those on shipboard. Would compounding not be useful in that instance? Mr. Mannock seemed to be averse to compounding for several reasons, but he could assure him that the case before them was one of actual experience, and there was no doubt that as far as wear and tear was concerned it was reduced to a minimum. He was surprised that the buffer arrangement was disparaged, because he had certainly seen shocks in cranes prevented by the application of this arrangement. As regards the margin of safety in boilers, he thought it had been amply proved that there was no greater risk with a high pressure boiler than with one working at a low pressure.

Mr. W. J. Jenkins observed that he had had considerable experience in the use of wire ropes, but for a different purpose from that before the meeting. His experience was mainly in the transmission of power, and he had frequently been astonished to hear the length of time a wire rope would run when used over the very small pulleys of hoists and cranes. The life of a rope depended on two factors besides the direct tension, viz.: the number of times the rope was bent round pulleys, and the amount of stress caused thereby. For the transmission of power by wire rope it was necessary to have large driving pulleys, and almost equally necessary to have large supporting pulleys, if the latter could not be done without, otherwise it would often be found that a small supporting pulley was breaking a rope to pieces owing to frequent repetition of bending stresses, when the rope would have lasted years under the stresses caused by the load and the bending round the large driving pulley. He agreed with Mr. Mannock that the diameter of the pulleys depended more upon the diameter of the wire of which the rope was made than upon the diameter of the rope itself. It was interesting to have Mr. Mannock's experience of the practice in colliery winding to allow the pulley to be 1000 times larger in diameter than the diameter of the wire in the rope. That rule would give too small a diameter for very satisfactory working in the transmission of power. A very common rule for this purpose was to make the *radius* of the pulley 850 times the *diameter* of the wire in the rope, or 70 per cent. larger than Mr. Mannock's rule for winding. This increase in size was no doubt necessitated by the more frequent bending due to the constant running of a rope transmitting power as compared with the frequent pauses in winding.

When ropes were first used for transmission on the continent, iron was the material of which they were made; when steel ropes were used to take the place of iron, the engineers naturally reduced the section somewhat in proportion to the tensile strength of the stronger material, and the result was that the steel rope was not so satisfactory as the iron. But when steel ropes of the same section as the iron ones were tried, they lasted one third longer. The total stress on the iron ropes (including stresses due to the useful load, initial tension to get the

necessary grip for driving, bending stresses and stresses due to centrifugal force) was 11 tons per square inch of metallic section.

Many people underestimated the importance of having supporting and carrying pulleys of ample size, believing that it was only the driving pulley that mattered. This view was actually set forth in some books on cable tramways, but the vital importance of the subject had been found out by English tramway engineers, else we should not hear of 20 feet pulleys being laid in streets to direct the cable round very easy bends.

By keeping the stresses in a steel rope down to the same figure as was usual in the continental practice, viz., 11 tons per square inch, engineers found that the steel would last 33 per cent longer than the iron ones and would last 18 months, doing, therefore, 33 per cent more duty for the same weight of metal, though if the stresses reached a figure proportionate to the extra tensile strength the ropes rapidly gave way.

It was exceedingly difficult at first to believe the theory of this subject, but practice soon confirmed its accuracy; and he recommended the members to make a calculation for themselves to find the amount of stress due to bending a $\frac{1}{16}$ inch wire round, say, a 12 inch pulley; after which, if they were not astonished he should be surprised, as he simply would not credit his own figures at the first attempt. That was why he found it astonishing to hear of the long life of the ropes used by Mr. Donald; it could only be accounted for by the intermittent character of his work in comparison with transmission at higher speeds and constant running.

His experience of wire ropes was that they were not very elastic except in long lengths, and he had seen records and diagrams of the effect of the interposition of a spring between the cage and the winding rope in a colliery, that shewed the snatch at the starting of the load to be very much reduced by the action of the spring. It was also the fact that couplings of traction and locomotive engines were protected by the addition of a spring even of a very limited range; and every engineer who had had experience in dealing with dynamic loads must be aware of the immense value of the gradual easing of the moving load by the action of a spring.

On the continent, springs, in one form or other, were almost universally used on cranes of any size and with very good results.

On the motion of Mr. Boswell, a vote of thanks was accorded to Mr. Donald for his interesting paper.

Mr. D. B. Donald, in replying, said he could hardly concur with the opinion expressed that the majority of the saving stated in his paper was due to the boiler, because he was certainly under the impression that the compound engine must be credited with the greatest amount in preference to the boiler, in this wise: 120lbs. pressure would not be economical if simple engines were used, because in cranes the steam must be carried more than half-stroke to allow of readily starting from any position, and little therefore of the benefits of expansion were secured. The compound system enabled the accomplishment of the latter to a much larger extent, and was mainly instrumental in the economy due to the high steam pressure.

The remarks respecting intermittent working, and whether compounding under these circumstances was justifiable, were best answered by giving a precedent, which we have in the case of pumping engines for supplying water under pressure for hydraulic machinery at docks, on board ship, etc., as they were as intermittent in their working as crane engines. During the last 10 years compound engines have been used with great success in preference to simple for this purpose, even in South Wales where coal is so cheap. Careful tests have conclusively shown that the saving effected fully justified the use of the compounds.

With reference to the remarks about range of temperature, Mr. Mannock was evidently mistaken, the economy of multi-cylinder engines being largely due to the reduction of such range in each cylinder. In the case in question the cut-off is at about ⅛in. stroke, and the range of temperature is therefore low in each cylinder; but the *total* range was much more than if 120lbs. pressure was used in simple engines and cut-off at ⅛in. stroke, being for the compounds 76 deg. as against

26 deg. for the simple; the latter were therefore not so economical.

It was also well to note that crane engines were as a rule not overhauled unless absolutely necessary, and it was evident, under similar conditions of wear, the compounds had a decided advantage to check leakage between the boilers and the atmosphere, any steam passing the high-pressure valve and piston being caught by the low. He might say that they had had no trouble with the bearings, at least not more than could be naturally expected from cranes working under such hard conditions as those referred to.

As regards the remark as to the size of the boiler, he admitted that in future cases he should be disposed to make it rather larger, though in this respect it must be borne in mind that the first cost would be increased, which was of considerable importance. Mr. Mannock seemed to be under the impression that because the springs were not of much avail in colliery practice they were equally inapplicable in the case under consideration. Respecting that point, however, he (Mr. Donald) must say that the rope which goes down a colliery is much longer than that used in a steam crane, and in the latter case the shortness of the rope was compensated by the springs. During the last five years, only one spur wheel had given way in the cranes, and he attributed that good result to the adoption of the springs. In reference to Mr. Boswell's remark that there were many other ways of improving cranes besides compounding, he could only say that he should be pleased to hear of them; at the same time he thought it would be readily admitted that a saving of £40. per annum in fuel, due to the adoption of the compound system, was not to be despised.

DIAGRAMS.

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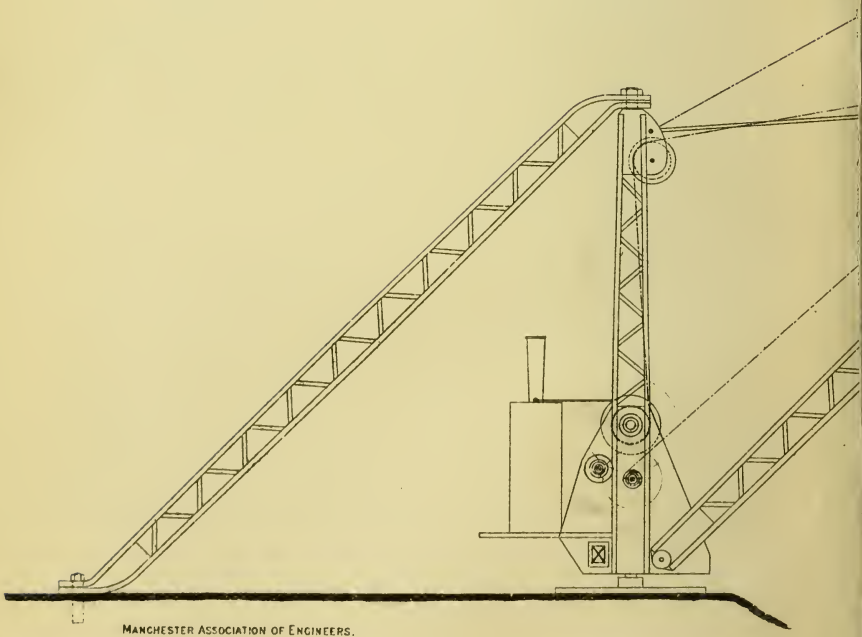
To illustrate Mr. D. B. DONALI

20 TON STEAM CRANE FITTED WITH FLYING JIB



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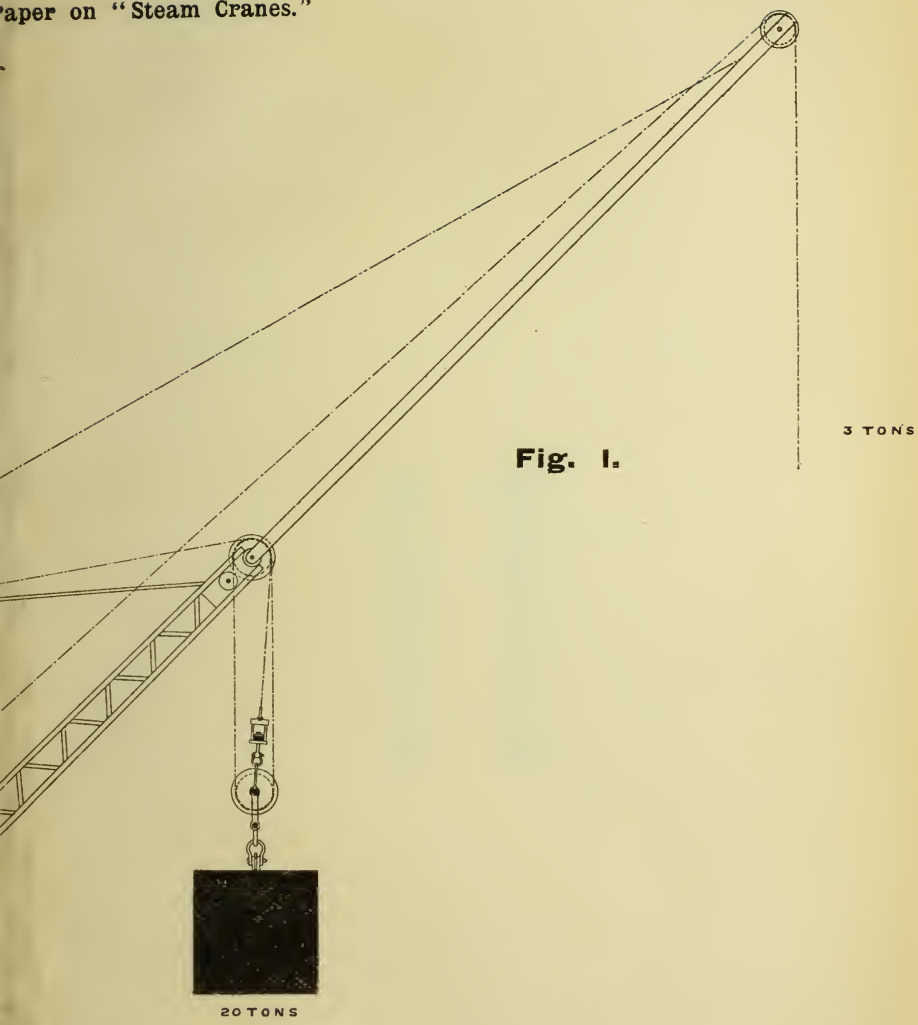
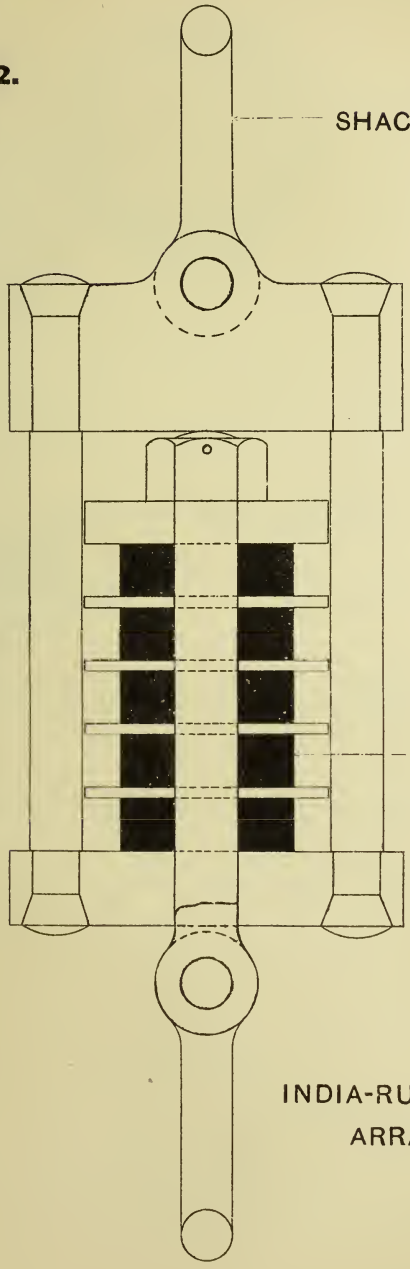


Fig. I.

To illustrate Mr. D. B. DONALD'S Paper on "Steam Cranes."

Fig. 2.



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NEW METHODS

OF SIGNALLING BY RAILWAY PASSENGERS

AND

SLIP COACH ARRANGEMENT

OF THE VACUUM AUTOMATIC BRAKE.

A COMMUNICATION

BY

Mr. GEORGE KIERNAN,

On 22nd NOVEMBER, 1890.

AT THE GRAND HOTEL, MANCHESTER,

MR. THOMAS DANIELS

IN THE CHAIR.

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NEW METHODS OF SIGNALLING BY RAILWAY PASSENGERS AND SLIP COACH ARRANGEMENT OF THE VACUUM AUTOMATIC BRAKE.

A fortnight ago some interesting and important experiments took place on the Manchester, Sheffield and Lincolnshire Railway, in the presence of Colonel Rich and Major-General Hutchinson, who attended in their official capacity as Board of Trade Inspectors. The trials were also witnessed by a large number of Locomotive and Carriage Superintendents, and other Railway Officials.

The experiments were first, for the purpose of practically testing the new means now being adopted on the Manchester, Sheffield and Lincolnshire Railway, for passenger communication with the driver and guard. A second series of experiments took place to demonstrate the latest arrangement for the application of the Vacuum Automatic Brake to slip vehicles. These experiments being of great public interest and importance, our President, a few days ago, expressed a desire that I should describe them to this meeting.

The short time at my disposal will not permit of my going very fully into these subjects; consequently, I shall only be able to give a brief description of them.

It is a general complaint amongst the travelling public, that in case of necessity, it is almost a waste of time to attempt to communicate with either the driver or guard of a train, by means of the usual cord which is the chief contrivance in use in this country.

That a reliable means of communication is necessary will be proved, if proof be required, by referring to one case only, viz:—The railway accident which occurred on July 14th, 1888, at Hyde Junction, on the Manchester, Sheffield and Lincolnshire Railway.

In connection with this accident, Mr. Pollitt, the general manager of the railway company, addressing the coroner's jury said:—"The question of what was the best means of "communication between the passengers and those in charge of "a train was one of the most difficult that had been considered "by railway companies for some time past. So difficult "was it that the Board of Trade had not felt they were "justified in requiring any company to supply such means of "communication, except in cases of trains which ran without "stopping for a distance of 20 miles. No end of experiments "had been tried, regardless of cost, by railway companies in "common, with a view of ascertaining the most complete and "satisfactory system of providing communication. The Man- "chester, Sheffield and Lincolnshire Railway Company had not "lost sight of this important question, and they had on many "occasions considered what steps would secure the best "possible means of communication. On some of their trains "they had tried an electrical method; that had not been "altogether a success. He thought, however, they were in a "fair way of attaining the object in view by another process. "He could only assure the jury that their recommendation "would be taken most seriously into consideration, and "anything which could be done by the company to ensure a "complete and satisfactory system would be adopted."

And Major-General Hutchinson, in reporting on this accident to the Board of Trade, concluded as follows:—"This collision "would most probably have been prevented had there been "means of communication between the passengers and the "driver and guard of the train. . . . As the train was one "which did not run 20 miles without stopping, there was no "statutory obligation on the Company to provide any means "of communication, but it is much to be desired that in view of "this collision, and of other accidents and cases which have

"occurred from time to time—in which trustworthy means of "communication would have been most valuable—some fresh "legislative action may shortly be taken, making it compulsory "that in all trains, irrespective of the distance they are "running, a satisfactory means of communication should be "provided between passengers and drivers and guards of "trains."

The South Eastern Railway, and the London, Brighton and South Coast Railway have adopted an electric communication, and many other inventions have been tried, but so far as this country is concerned only the cord and the electric have been used to any extent. With an electric communication, if the apparatus is to be of any use, there must be a connection between the coaches to secure continuity, and if one of these connections be left uncoupled it would at least cut off a portion of the train from the engine, so far as signalling is concerned.

The fewer the number of connections which have to be made between the vehicles of a train the better. Consequently if some existing means of continuity can also be used for signalling, greater simplicity and reliability will be secured.

As the Board of Trade intend very shortly to insist upon every vehicle in a passenger train being under the control of the driver through an automatic brake, and as this brake can be arranged for application in any part of a train, it is at once a means of communication which can be guaranteed for continuity whilst the train is running.

The principle of the apparatus which I propose to describe is based upon this means of communication, *i.e.*, by the use of the continuous brake. I do not suggest that employing the brake pipe for communicating is a novel plan. The method was suggested and tried many years ago, but the mechanism adopted did not give satisfaction.

It was to the Simple Vacuum Brake that Mr. Gresham first adopted this system, the intention being to communicate through the pipe by means of the tell tale gauges which were placed on the engine and in the van. These gauges were so arranged that when a signal was given they displayed a red

tablet marked with the word "wrong." The brake was arranged so that the giving of a signal in no way interfered with the use of the brake for stopping purposes,

Subsequently a similar plan was applied to the Vacuum Automatic Brake.

In this case, however, the brake was somewhat slowly but surely applied by a passenger breaking a small glass disc, such a disc being placed in each compartment of a coach. This was done by striking a rubber ball hanging on a kind of knocker and placed in front of the disc of glass. After the disc was broken, it was impossible for the brake to be again released unless the carriage had been visited by the servants in charge of the train and a new glass inserted, or the connection cut off by closing a cock. This plan possessed features of very great importance, in that it was eminently simple, and the broken glass was a very sure indication of the compartment in which the communication had been made.

A further improvement was, however, desired, it being considered advisable, that in addition to calling the attention of the driver and guard, a visible signal should be shown on the outside of the coach as soon as the apparatus was brought into use. This has now been successfully accomplished.

It is not a wise proceeding to put into the hands of passengers the power of stopping a train when and where they consider necessary, though, as I have already explained, no difficulty whatever exists in doing so through the Automatic Brake.

The control of a train must remain in the hands of the servants of the railway company and under their responsibility, and it cannot safely be delegated to the public, who would often imagine danger when none existed. Only under very extraordinary circumstances should passengers in a railway train be enabled to compel a driver to stop the train, or rather to stop it themselves.

I shall endeavour to show how the latest arrangement carries out this desideratum, and I have compiled the following

requirements which are what I consider necessary for an efficient means of communication:—

1st. That a passenger in any compartment of a train should be able to communicate with the driver and guard.

2nd. That in doing so signals should be displayed at both sides of the train, so that the guard may easily discover where the communication was made.

3rd. That these signals when given should not be capable of being released by the passengers.

4th That when a communication is made, the driver should be able to run his train, if necessary, to a place of safety before stopping it.

5th. That should something so serious occur as to cause communications to be made from a number of coaches, these communications should of themselves stop the train.

I will now describe the apparatus exactly as it was in use at the trials:—

Each coach is arranged, see Figs. 1, 2 & 3, with a small air admission valve, which is connected by a ⅜in. pipe to the 2in. continuous brake pipe. When this valve is opened, it admits sufficient air to the brake pipe as will reduce the vacuum from 20ins. to 10ins. of mercury. This reduction of vacuum is indicated by the gauges placed on the engine and in each van, and is equivalent to the application of the brake throughout the train, to the extent of about half its power. When the driver finds a communication has been made—which he sees by the indication of his guage and better still, by the fact that his brake is on and he is unable to release it and keep it off in the usual way—he can stop at once, or if the train be in a tunnel or in some other inconvenient or perhaps dangerous place, he can by applying his large brake ejector, exhaust from the brake pipe the same amount of air as is admitted through the communication valve, and thus practically release the brake and so run to a place of safety.

The valve can be opened from any compartment in the coach, by the partial turning of a light hollow rod of about ½in.

diameter, which is usually placed under the cornice on one side of the coach, and is sufficiently flexible to work with the necessary amount of freedom without difficulty. On this rod at one end of the coach is placed a small signal arm, the end of which is shaped in a circular form and painted red.

In its normal position this signal arm rests in a cover and is hid from sight. The partial turning of the rod throws out the signal to the side of the train. On the opposite side of the coach is placed another signal of similar shape also resting under cover, the two signals being connected together by a light wire rod and copper chain passing across the end of the coach, so that the two signals work in unison and are both visible—one on either side of the train—when a communication has been made.

The valve is placed on the end of the coach midway between the two signals. It is a hinged valve made in the form of an inverted T and is opened by a collar which is fixed on the wire rod, coming in contact with its vertical arm. When the signals are released the valve falls again upon its seating by its own weight.

There only now remains for me to describe the system adopted for turning the rod under the cornice from each separate compartment. This is accomplished by a copper chain from each compartment being attached by a split pulley clipped on the rod by 4 screws. The chain is then conveyed over and under small guide pulleys, so as to bring it to the centre and under the hat rack. It is then attached to a ratchet disc fixed at the back of a handle, which, for the sake of finish, is placed in front of a wooden pattress.

It will be evident that by pulling down the handle its movement will be conveyed through the chain to the rod under the cornice, the turning of the rod throwing out the signals and opening the air-valve as already described. The handle is held down by the ratchet until released by the guard's key.

The signals of course indicate the coach from which the communication has been made, and as no one handle is affected by the movement of another the position of the handle must denote the compartment.

The trials made on the 8th instant were as follow:—

A handle was pulled down in one compartment, the driver having been instructed to whistle when he found a communication had been made. The whistle of the driver was heard in five seconds. The signal was then released and the train continued its journey.

The next experiment was to test how soon a driver could be communicated with and the train stopped in case of emergency, and it was found that the rapidity with which the communication could be made and the powerful brake with which the train was fitted, this could be done in a remarkably short space of time. The whole operation occupied only 22 seconds from a speed of 40 miles per hour.

The next trial was practically a repetition of the first, but in this case the Board of Trade Inspectors were on the foot plate of the engine for the purpose of noticing the warning received by the driver.

Next came a communication which the driver had been instructed not to notice, or rather, he was not to take any means of stopping his train or of overpowering the partial application of the brake. This proved beyond doubt that the signal was a very definite one as the train was stopped in 37 seconds with the engine under full steam. In this case also the speed was 40 miles per hour.

Another trial demonstrated successfully that the driver, though he had received a communication, was able to keep his train running by using the large ejector of his brake to overpower the admission of air. This experiment was intended to represent a communication being made on a part of the line where the driver considered it dangerous or undesirable to stop his train, and demonstrating that the stopping of the train had not been put in the hands of unscrupulous passengers.

It was then assumed that something very serious had happened to the train, and that passengers in several coaches, seeing the danger, had brought the apparatus into use. It was then found that under such extraordinary circumstances the driver was unable to overpower the brake in any way.

I have no doubt that when the Inspectors of the Board of Trade make their report, it will be found to be in every way favourable to this new system of signalling.

I may add that many arrangements of mechanism have been tried with this communication, and the one I have described is the one adopted by the Manchester, Sheffield and Lincolnshire Railway.

There is, however, one other plan I should like to refer to and that is the method of using audible instead of visible signals. By this plan greater simplicity is secured. One valve is placed in the partition of a coach so as to serve for two compartments, and the pushing in of a knob or button from either compartment opens the air valve. The air in passing into the brake pipe through the valve is caused to flow through a horn or whistle and so produces an audible signal. This signal continues to sound until the valve has been closed by the guard's key.

SLIP COACHES.

I shall not require to occupy much of your time in explaining the trials of the improved means of using the Vacuum Automatic Brake on slip carriages.

It is well known that in the Vacuum Automatic Brake, no cocks or valves are placed in the continuous pipe, so that if it be necessary to cut the train in two portions without applying the brake, special methods of closing the pipes must be adopted.

The Board of Trade have signified to the Railway Companies that in *all* cases the rear vehicle of a train must have applied to its wheels a brake which is under the control of the driver. As slip coaches are of necessity at the rear of the train, it follows that they must be under the control of the continuous brake so long as they remain an integral part of the train.

The plan now adopted, see Fig. 4, for securing this end is neat, simple, and very effective. It was found to be in every way satisfactory when tested on the 8th instant, by Colonel Rich and Major-General Hutchinson. It consists of two double couplings, each containing a plug-cock with a capacity of about ·75 square inch. This size of passage is large enough for all purposes even for an emergency stop from the slip van, the amount of air which

can flow through it being sufficient to open the van valves. These cocks or double couplings are placed between the ordinary hose pipe couplings to which they are secured by means of light chains attached to the swan necks of the brake pipes. The chains are so arranged with a hook at one end and a ring at the other that they can be readily fixed to any coach. A lever is fixed on the plug of each cock, the cock having the longer lever coupled to the slip carriage. A cord passing through the end of the slip van is attached to this lever, the bottom part of which is made in the form of a cam, and as the lever is moved by pulling the cord—thus closing the cock—the cam comes in contact with a roller on the corresponding part of the lever placed on the other cock.

This arrangement of levers secures the working of the two cocks in unison, it being impossible to open or close one cock without opening or closing the other.

A further advantage is also gained, for when the cord has been pulled far enough to close the cocks, an additional pull will uncouple the pipes, the weight of the couplings and cocks being supported by the chains.

It is evident that should the train accidentally divide at the slip coupling the pipes will uncouple without closing the cocks and thus the brake will be applied automatically to all parts of the train.

The trials which took place were for the purpose of showing:

1st. That the cocks did not interfere in any way with the continuous working of the brake from the engine.

2nd. That the brake remained automatic when a break loose occurred at the slip coupling.

3rd. That the cocks could be closed and the coaches slipped from the train without applying the brake, which remained ready for use on both portions.

These experiments were also eminently successful, and proved that a difficult problem had been solved in a very simple and satisfactory manner.

Mr. H. Pollitt, (Manchester, Sheffield and Lincolnshire Railway), in the course of the subsequent remarks, said:— The new signalling appliances had now been in use on the Manchester, Sheffield and Lincolnshire Railway for the past 14 months, on the train running between Manchester and London, and altogether it had been used about 23 times. It was a great improvement on the cord system, which, besides being practically out of the reach of anyone who readily needed it, entailed a great delay at junctions every time the carriages changed systems. As a matter of fact, notwithstanding the many occasions upon which the cord might have been used with advantage by a passenger, he could find no record of it so being applied.

Messrs. Gresham and Craven's ingenious improvement concerned them all, since it could be effectually used in the case of sickness or outrage in a train, or even if the carriage axle broke. On the system having the official sanction of the Board of Trade, it would be adopted universally on the Manchester, Sheffield and Lincolnshire Railway.

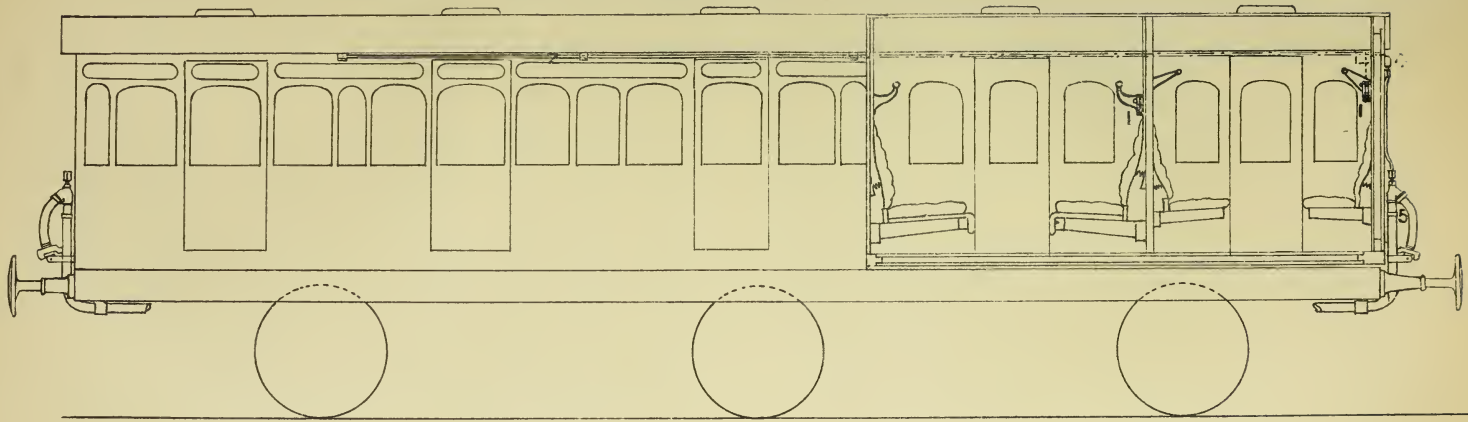
On the motion of the Chairman (Mr. T. Daniels), seconded by Mr. E. G. Constantine, a cordial vote of thanks was passed to Mr. Kiernan, which he briefly acknowledged.

PASSENGER COMMUNICATION ON RAILWAY TRAINS.

(GRESHAM'S PATENT).

SIDE VIEW.

Fig. 1.



1 *Communication Handle.*
2 *Rod under Cornice.*
4 *Air Valve*
5 *Brake Pipe*

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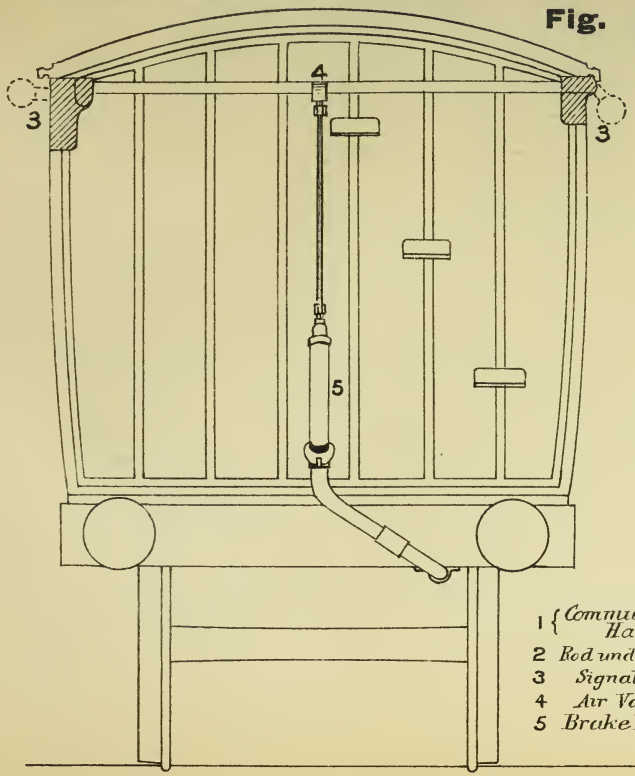
PASSENGER COMMUNICATION ON RAILWAY TRAINS.

(GRESHAM'S PATENT).

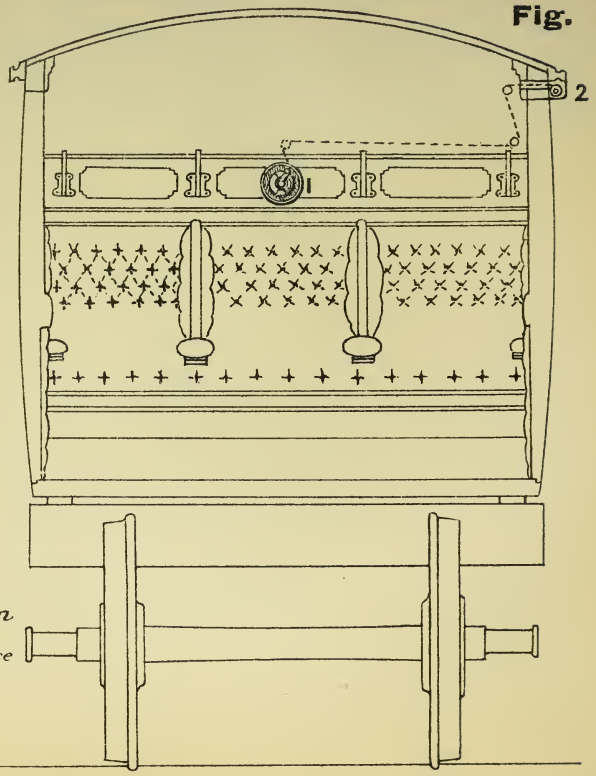
VIEW AT END OF COACH.

Fig. 2.



CROSS SECTION THRO' COMPARTMENT.

Fig. 3.



1 { *Communication Handle.*
2 *Rod under Cornice*
3 *Signals*
4 *Air Valve*
5 *Brake Pipe*

SLIP COCKS
OF
VACUUM AUTOMATIC BRAKE.
(GRESHAM'S PATENT.)

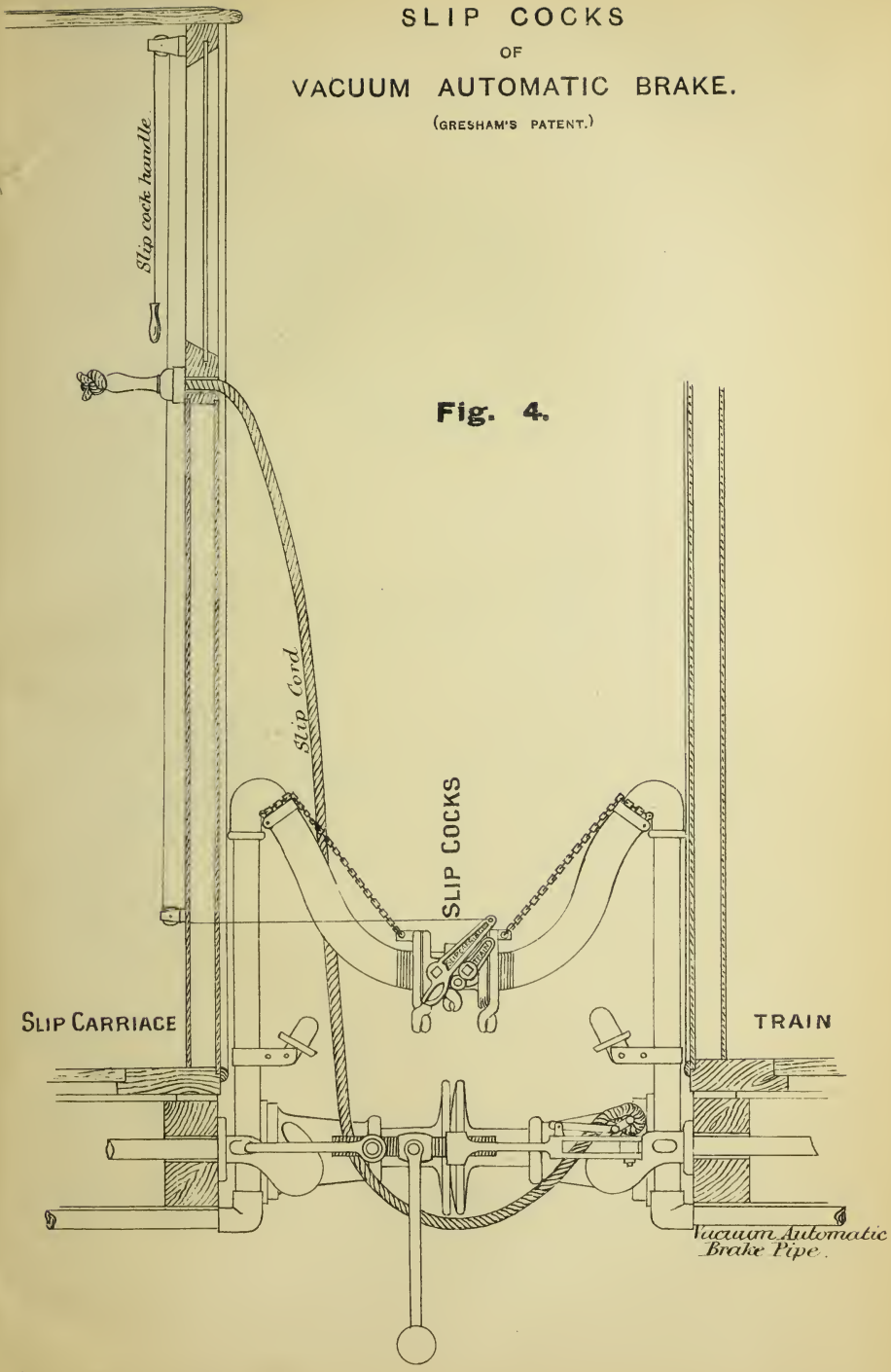


Fig. 4.

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1891.

President:

Mr. JOHN WEST, M.Inst.C.E.

Past-President:

Mr. SAMUEL DIXON, M.Inst.M.E.

Treasurer:

Mr. HENRY MAINWARING.

Trustees:

Mr. G. CARTER,	Mr. JAS. WALTHEW,
,, Ald. E. ASQUITH,	,, T. ASHBURY C.E.,

Mr. Alderman W. H. BAILEY, J.P.

Council:

Mr. E. G. CONSTANTINE,	Mr. F. WALTHEW,
,, J. W. EVES,	,, E. MARSHALL,
,, T. WILLIAMS,	,, A. REA.

Librarian:

J. GIBBON,

133, Elizabeth Street, Cheetham.

Secretary:

FRANK HAZELTON,

63, Barrett Street, Old Trafford.

Annual General Meeting

HELD AT THE

GRAND HOTEL, MANCHESTER,

13th December, 1890,

Mr. JOHN WEST, M.Inst.C.E., President,

IN THE CHAIR.

The minutes of the previous meetings having been read and confirmed, and signed by the President,

The Chairman announced to the meeting the result of the ballot for the election of new members.

The election of President and other officers of the Association was next taken, with the result as set forth on opposite page.

Resolved unanimously,—"That the cordial thanks of this meeting be given to Mr. John West, for the deep interest he has taken in the welfare of the Association; for the excellent manner in which he has discharged the duties attaching to the Office of President during the past year, and especially for the courtesy and kindness he has uniformly displayed in the chair."

Mr. West acknowledged the compliment.

Resolved unanimously.—"That the thanks of the Association are justly due and are presented to the Past-President and other Officers of the Association for their co-operation with the President, and for their zeal on behalf of the Association during the past year."

Messrs. Asquith and Mainwaring acknowledged the compliment.

Resolved unanimously,—"That the Annual Dinner be held as usual; all arrangements to be left in the hands of the Council."

Annual Report of Council.

1890.

The Council in presenting their 35th Annual Report, have again reason to congratulate the members upon the continued advance and prosperity of the Association.

To the membership roll during the year have been added—

1 Honorary Life Member.
7 Honorary Annual Members.
11 Ordinary Members.

Total 19

but taking into account the loss by death, resignation, and erasure, the effective addition to the membership roll amounts to 6, bringing up the total number of names of all classes on the roll to 335, namely :—

25 Honorary Life Members.
94 Honorary Annual ,,
216 Ordinary ,,

Upon reference to the Financial Statement as certified by the auditors (see appendix), it will be seen that the balance standing to the credit of the Association after payment of all accounts due up to the 31st December, amounts to £3,062 16s. 0d., as against £2,872 14s. 9d., at the close of the preceding year, thus showing a surplus of £190 1s. 3d. on the year's working; notwithstanding the deduction of the sum of £52 8s. 2d., loss arising from the winding up of the Consolidated Building Society.

It is with profound regret the Council have to record that during the year death has removed the following members, memoirs of whom are appended on pages 249 to 252. In accordance with resolutions, letters of condolence and sympathy

have been forwarded to the widows and families of the deceased members :—

Adamson, Daniel - -	Hyde.
Cottrill, R. N. - - -	Bolton.
Crighton, Duncan - -	Manchester.
Taylor, W. - - -	Oldham.
Welch, F. B. - - -	Manchester.

The following gentlemen have resigned their Membership in the Association during the past year :—

Chatterley, G. - - -	Accrington.
Harcourt, O. S. H. - -	Bolton.
Rylands, D. - - -	Barnsley.

The following gentlemen have ceased to be Members of the Association during the past year :—

Goodall, E. - - -	Altrincham.
Haley, H. - - - -	Manchester.
Hargreaves, J. - - -	Royton.
Miles, J. H. - - -	Stalybridge.
Nicoll, James - - -	Hulme.

The following gentlemen have been added to the Membership Roll during the year :—

Honorary Life Member.

Ramsbottom, John - -	Alderley Edge.

Honorary Members.

Atherton, Giles - - -	Stockport.
Barber, W. - - -	Manchester.
Burnet, L. - - - -	Glasgow.
Fulton, D. - - - -	Manchester.
Goodfellow, F. F. - -	Hyde.
Günther, J. - - -	Oldham.
Jones, M. G. - - -	London.

Ordinary Members.

Bartlam, J. - - -	Stockport.
Bodmer, C. H. - - -	Newton-le-Willows.
Boyle, J. - - - -	Manchester.
Cooper, F. S. - - -	Do.
Earnshaw, E., jun. - -	Heywood.
Halstead, J. H. - - -	Manchester.
Hill, G. F. - - - -	Bolton.
Lowe, E. J. - - -	Manchester.
Parry, R. - - - -	Do.
Quicke, W. G. - - -	Do.
Smith, W. W. - - -	Do.

The Council wish to thank those gentlemen who have devoted their ability to the preparation of papers, for the efforts made in the production of valuable literary contributions to the Association. They trust that the number and importance of these papers may be still further augmented in the future. Most of the members being engaged in some particular branch of Engineering are able to add to the knowledge of their fellow members. The Council hope that all will do their best, by the contribution of papers on Engineering subjects which have come under their special observation, to aid in advancing the interests of the Association.

PAPERS READ AND DISCUSSIONS HELD DURING THE YEAR.

11th Jan.—Inaugural Address by the President, Mr. John West, M.Inst.C.E., of Manchester.

25th Jan.—On "Evaporation of Lancashire Boilers," by Mr. M. Longridge, M.A., M.Inst.C.E., of Manchester.

22nd Feb.—On "Continuous Brakes: their recent development," by Mr. G. Kiernan, of Manchester.

22nd Mar.—On "The Friction and Lubrication of Cylindrical Journals," by Prof. J. Goodman, Assoc.M.Inst.C.E., of Leeds.

12th April.—On "Feed Water, its effect on Boilers and its Treatment," by Mr. E. G. Constantine, M.I.M.E., of Manchester.

25th Oct.—On "Graphic Tabulation and some relations of Art to Engineering," by Mr. H. Guthrie, C.E., of Manchester.

8th Nov.—On "Automatic Expansion Gear," by Mr. J. J. Harper, of Northwich.

22nd Nov.—On "Steam Cranes," by Mr. D. B. Donald, of Cornwall.

" —"A New Method of Signalling by Railway Passengers," by Mr. G. Kiernan, of Manchester.

29th Nov.—"Reminiscences of the visit to the United States by the Iron and Steel Institute." Messrs. T. Ashbury, S. Dixon, and other Members.

All the foregoing papers and discussions with the exception of the last mentioned will be published and issued to the members.

The attendance of the members at the reading of the above papers has been extraordinarily large, which is a satisfactory indication of the interest evinced in this department of the Association.

The Thirty-fourth Anniversary Dinner was held on Saturday, Feb. 8th, at the Grand Hotel. Mr. John West, the president of the Association, occupied the chair, and amongst the large company present were the Mayor of Manche ster (Mr. Ald. Mark), Mr. J. Ramsbottom (Alderley Edge), Mr. L. P. Nott, Mr. T. Ashbury, Mr. Samuel Dixon, ex-president of the Association; Mr. Alderman Asquith, Mr. J. Craven, Mr. Alderman Bailey, Mr. H. E. Gresham, Mr. J. Walthew, and Mr. Ball (Rochdale), president of the Manchester Association of Gas Engineers. The general company numbered 111.

The Chairman, in proposing the loyal toasts, said the Prince of Wales gave a not inconsiderable portion of his time to works in connection with their profession. They hoped ere long to have the pleasure of seeing him open that great engineering work the Forth Bridge—(hear, hear)—and a few years hence they trusted they would see him once more amongst the people of Manchester upon the occasion of the opening of the Ship Canal.—(Applause.)

Mr. Alderman Bailey proposed "Our Municipal Corporations." He remarked that the city of Manchester had taken an imperial position in the development of the human race. She had indeed taken a position in the history of mankind similar to that occupied by Florence in the sixteenth century. In no city in the world would they find so many men who had investigated the laws of nature, and who had been conspicuous in the history of literature and science, as were to be found in Manchester in the last hundred years. Manchester to-day had the finest town hall perhaps in the world, and her municipal administration was conducted with the greatest intelligence and ability.—(Hear, hear.)

The Mayor of Manchester responded to the toast. He said he did claim for Manchester and Salford that they stood in the foremost rank of municipal corporations, and that there was an energy and force, and a desire to keep pace with the reasonable expectations of engineers displayed by those bodies. He hoped they would not be disappointed. In a company like that he, as a mere layman, spoke with considerable diffidence; but he could not help recognising the indebtedness, not only of municipal corporations but of the community at large, to the engineering and mechanical sciences. We accepted the results of their ingenuity, their inventions, and their experiments as a matter of course. We were glad to cross the Atlantic in six days and a half instead of nine, and to go to London, with enormous economy of time, in four hours and a quarter, instead of the considerably greater length of time that the journey formerly occupied, without thinking perhaps to whom we were indebted for that saving of time, which meant money.—(Hear, hear.) He was not a practical man, but he believed that so rapid was the advance of engineering and mechanical science that a cotton mill constructed with all the best appliances of machinery twenty years ago would not stand a chance in the race of competition of the present day. He believed no one wanting to compete in cotton spinning to-day would think of purchasing a mill that was built almost irrespective of cost twenty years ago.—(Hear, hear.) That marked an advance of science in connection with machinery which was exceedingly rapid. There were enormous improvements in the applications of the forces which heat and water implied which could scarcely be enumerated. There were pumps, lifts, and presses which were not dreamed of even twenty years ago; and for all these matters, which meant great advantage in the economy of labour and in the saving of time and expense, we were indebted to the engineer. And yet, withal, as in the case of the substitution of the locomotive for the old stage coach, there was no dimunition in the amount of labour, but an increase of work in the busy hive of industry in which we were engaged.—(Hear, hear.)

Mr. Alderman Asquith proposed "Prosperity to the Association." As one of the original members of the Association—which, he said, started with fourteen members—he traced its

rise and progress to its present important position. He was glad that the Association was so well represented in connection with the Manchester Ship Canal, several of its members occupying positions on the board of directors and in the engineering department of that great undertaking. He trusted that the work would be carried to a successful issue, and he was sure that Association would give it all the assistance possible. (Hear, hear.) He believed without the help of engineers the canal would be of little use. The engineers of Manchester and the district in this and other matters would show the country that they were not behind those of any other locality.—(Hear, hear.)

The Chairman, in reply, said he believed that the improvements which had been made in the engineering profession in the past would be continued in the future if they would only put their shoulder to the wheel. It had been the custom in this country to believe that there was no nation that could compete with us. That notion was all very well if it was backed up. We must continue to train ourselves, remembering that there were other nations pressing us very hard. There was an impression that if Englishmen used their intelligence and their energy in the future as they had done in the past we might hold our own. It depended, however, very much upon how we equipped ourselves, and in connection with that observation he desired to impress upon those present the great importance of technical instruction. During the past year a bill had been passed by the Legislature with the object of assisting corporate bodies to help people to get a better knowledge of mechanical science than they had had hitherto, and he trusted when the time arrived the Mayor of Manchester would give his assistance in the matter of enabling young men to have information imparted to them which would permit them individually to improve themselves in order that they might the better compete with foreign nations.—(Hear, hear.) The system adopted by some other countries with reference to the imparting of education was in some respects no doubt superior to that which was obtained in this country. We had got on so well in the past that some people thought we could rest upon our oars; but as surely as we did that we should be left out in the cold.—(Hear, hear.)

We had technical schools, and the Whitworth Trustees were doing a good work. Owens College also was an important element in the matter. If these various institutions associated themselves together in this work, he believed the best results would accrue, because what they wanted was unity, which was strength.—(Hear, hear.) He was not satisfied with the training of our young men at the present time. While he agreed that they should be trained scientifically and that they should acquire as much technical knowledge as possible, that which was of the greatest value to them was practical knowledge.—(Hear, hear.) There was no district in England where it was more necessary that something should be done in the direction he had indicated than that covered by the operations of their Association. There was no centre where there was so much engineering skill and where so many mechanical appliances were produced. Things in the engineering trade had taken a turn for the better, and he hoped the improvement would be continued. If there were no disturbances in connection with the workmen there would be a continuation of prosperity in the engineering business for some time to come.—(Hear, hear.)

Mr. T. Ashbury proposed "Our Guests."

The Mayor, in reply, asked how it was that in the matter of passenger elevators this country was so far behind America. In the United States it was possible, by means of their perfect system of lifts, to reach the sixth and seventh storeys of buildings with as much ease as to ascend to the first floor, and in consequence offices at the top of a building were almost of equal value with those on the ground floor. The matter, he considered, was a most important one, and it was one to which engineers in this country should turn their attention.

Mr. L. P. Nott also responded.

The Chairman, answering the question of the Mayor, said English engineers would have no difficulty in constructing the lifts if the architects would design buildings suitable for them. (Hear, hear.)

Mr. S. Dixon, ex-president of the Association, proposed "The Engineering Profession," and the toast was responded to by Mr. L. E. Fletcher and Mr. John Craven.

Mr. W. J. Jenkins submitted the toast of "Kindred Associations," to which representatives from Associations at London, Leeds, Newcastle, and Middlesbrough responded.

The health of the Chairman concluded the toast list.

LIBRARY.

The Council are pleased to report that the Library continues to fill a very important place in the Proceedings of the Association. The following new books have been purchased :—

Title of Book.	Author's Name.
Engineering Estimates, Costs and Accounts.	
Electrical Engineering.	Slingo & Brooker.
Engineers' Assistant.	
Fuel and its application.	Mills & Rowan.
Modern Hydraulics.	Armengand.
Modern Explosives.	Eissler.
Steam Boilers.	Peattie.
Turbines.	Armengand
Turbines.	Redtenbacher.
Waterways and Water Transports.	Jeans.
Water Engineering.	Slagg.

The Council have pleasure in acknowledging the following donations, and in expressing their thanks to the donors for the valuable and acceptable additions they have thereby made to the Library :—

History of the Manchester Waterworks. Bateman. Presented by Sir John J. Harwood.

Mechanical Exercises. Moxon (1677). Presented by Mr. E. Simpkin.

Modern Cotton Machinery. Presented by the Author, Mr. Joseph Nasmith, Member of the Association.

Red Hot Furnace Crown Experiments. Presented by The Manchester Steam Users' Association.

The Tabor Indicator. Presented by Messrs. Musgrave & Sons.

The Association exchange transactions with the following :—

American Institute of Mining Engineers.
Canadian Society of Civil Engineers.
Canadian Institute, Toronto.
Civil and Mechanical Engineers' Society.

Engine, Boiler and Employers' Liability Insurance Company.
Franklin Institute, America.
Institution of Civil Engineers.
,, Engineers and Shipbuilders in Scotland.
,, Mechanical Engineers.
,, Civil Engineers of Ireland.
Iron and Steel Institute.
Liverpool Geological Society.
,, Engineering Society.
Manchester Geological Society.
,, Steam Users' Association.
,, Statistical Society.
,, National Boiler Insurance Co.
" Literary and Philosophical Society.
Midland Institute of Mining, Civil, and Mechanical Engineers.
Mining Association and Institute of Cornwall.
Mining Institute of Scotland.
North of England Institute of Mining and Mechanical Engineers.
North-East Coast of Engineers and Shipbuilders.
Philosophical Society of Glasgow.
Royal Scottish Society of Arts.
Society of Arts.
South Wales Institute of Engineers.
Society of Engineers.

The following Publications are received periodically :—

Colliery Guardian.
Electrical Review.
Engineer.
Engineering.
Industries.
Invention and Inventors' Mart.
Iron.
Iron and Coal Trades' Review.
Marine Engineer.
Mechanical World.
Textile Manufacturer.

With the view of increasing the Library, the Council respectfully invite the members to make donations of books, original pamphlets, drawings, &c. To enhance its value, the Council are always willing to receive suggestions for suitable additions to the Library, entries of which may be made in the "Recommendation Book."

TAXATION OF MACHINERY.

At the June Half-yearly Meeting, in accordance with notice given on circular, Mr. Thomas Ashbury proposed the following resolution :—

> "That the members of this Association at their Half-yearly Meeting assembled, desire to record their unanimous approval of the Bill to amend the law relating to the taxation of machinery now before Parliament, and trust that it may be passed into law, and that the necessary local taxation of the country may be levied upon realised wealth and profit, and not upon the means by which that wealth or profit is created, or by any method that operates as a direct tax upon labour."

He said that this subject to some of them might seem to be rather outside ordinary business, but it had been suggested that the Association should make its voice heard with regard to the Bill for the rating of machinery now before the Houses of Parliament. As they all knew, in the rating of machinery there was a great deal of unfair pressure often put upon the owners of it. Machines should be implements for earning money and not subject to rating any more than the smaller tools of other trades, such as joiners' tools, &c. Petitions had been sent out from various parts of the country to the Government, and he asked them to pass the resolution.

Mr. James Walthew, in seconding the proposition, said it had always been a doubtful question as to what machinery should be assessed. Some time back, they would remember, there was a very strong attempt at a place on the Tyne to tax all the machinery belonging to shipbuilding yards, and a great deal of money was spent in taking the case to the House of Lords. The mill owners were quite prepared to go to the House of Lords sooner than be put down.

Mr. Samuel Dixon said they had had in Salford a practical instance of the inequality in the rating of machinery; his works had been rated at £300 over the actual rent paid. It was unnecessary to say they should not pay it.

Mr. Jos. Nasmith suggested that the resolution be sent to the Rt. Hon. W. H. Smith and all the six Manchester members of parliament, and also to Sir Henry James, the mover of the amendment of which notice had been given in Parliament.

The President thought it was very desirable that they should do their best to bring about a better state of things in reference to the rating of machinery. It was often the case that a man was sent down to assess machinery, &c., who knew nothing whatever about it. It was most absurd to tax the means by which they got their living.

The resolution was then carried unanimously.

Copies of the resolution were forwarded to the gentlemen named, and officially acknowledged.

DISCUSSION SESSION.

In accordance with the precedent of the last two years, the opening Meeting of the 35th Discussion Session took the form of a social gathering, and was held on Saturday, 11th October, at the Grand Hotel. About 80 members sat down to tea, and the remaining part of the evening was given up to conversation, diversified by vocal and instrumental music. Those taking part in the musical programme included Messrs. W. Spary, F. Walthew, Whittaker, Booth, Farrow, Sutcliffe and Bebbington. The president (Mr. John West) was in the chair, and in the course of a few remarks after tea, said that the Council had striven – and he thought the members would ultimately admit with some amount of success—to get every class of science and engineering represented in their programme for the session. Whether the session was a success or not, however, depended upon the members. Speaking generally, he might say that in matters affecting engineering Manchester was progressing favourably. More especially did he think this was the case with regard to technical education. There was no doubt, however, that unless the authorities looked well and wisely to the future and the need in this direction, a lot of money might be foolishly spent in the provision of too many seats of operation. For the purposes of technical engineering it would be better to have a very large school in the city, possessing good and substantial apparatus, than to split up this study and work amongst the existing board schools and the like institutions. —(Hear, hear.)

The Council desire to again draw attention to the two following resolutions which have met with their unanimous approval, and which they believe will have the acquiescence of every member:—

Transactions.—That the Transactions of the Association be issued in Annual Volumes, and that a member desiring to obtain any pamphlet immediately after reading may have such at cost price on application to the Secretary.

Papers read before the Association.—That with the object of enhancing the value of the discussions, members interested in the subject of a paper may have, on application to the Secretary, an advance proof of the same before the meeting. And that any member unable to be present may express his views in a written communication, such communication to be, at the discretion of the President, read to the meeting before printing.

VISITS.

During the year the members have made the following visits, condensed accounts of which are given on pages 253 to 256.

28th June.—The Manchester Ship Canal, Eastham Section.
Present, 150 Members and Lady Friends.

16th Aug.—The Manchester Ship Canal, Manchester, Salford and Barton Sections.
Present, 100 Members.

6th Sept.—Mr. Herbert Fletcher, Farnworth Bridge Colliery.
Present: 150 Members and Lady Friends.

In congratulating the members on the substantial progress made during the year just closed, as epitomised in this report, the Council believe that the liberal arrangements made respecting the literary department will give such an impetus to the Associations' work as to make each recurring year more successful; especially will this be attained if every member will try and assist in carrying out the primary objects for which the Association was founded.

OBITUARY.

Daniel Adamson was born in Shildon, in the county of Durham, in 1818, and studied engineering as a pupil of the celebrated Timothy Hackworth, locomotive superintendent of the Stockton and Darlington Railway. This pupilage lasted from 1835 to 1841. Mr. Hackworth, a man of acknowledged capacity, was the first railway locomotive superintendent in England, or in the world. Mr. Adamson subsequently acted under Mr. William Bouch as managing draughtsman and superintending engineer of the Stockton and Darlington works. During 1847, when he was 29 years of age, and the two following years he acted as general manager of the Shildon engine works of the Stockton and Darlington Railway Company. In 1850 he resigned his function of his own free will in order to become the general manager of Heaton Foundry, and during 1850 and 1851 prepared the plans and built a cotton mill at Stockport. He left Heaton Foundry to commence business on his own account in 1851, at Newton Wood and Newton Moor Ironworks, near Manchester, as engineer, ironfounder, boiler-maker, &c., and carried on an extensive business for 21 years, until the works became too small. In 1872 he erected new and more commodious engineering works at Hyde Junction, Dukinfield, near Manchester. These were afterwards enlarged, and exemplified in the fullest degree all the modern essentials of a great engineering establishment. The works cover nearly four acres, and employ over 600 men, whose wages amount to £40,000 per annum. Mr. Adamson distinguished himself as the patentee of a series of inventions extending over a period of thirty years. In 1852 he patented the flange seam for high-pressure boiler flues, which is used throughout the trade by the best boiler-makers, and is known as the "Adamson flange seam." He also patented improvements in the super-heating of steam between cylinders of compound engines, &c. In 1857 and 1858 he applied steel in the construction of locomotive boilers, and subsequently made over 2,800 steel boilers for working at pressures varying from 50lbs. to 250lbs. pressure per square inch. In 1858 he also patented hydraulic lifting jacks and the application of hydraulic power for riveting metallic structures. During 1861 and 1862 he built a triple-cylinder compound engine under a patent brought out by him, and in 1873 quadruple-action compound engines under a further patent for reducing and economising steam. In 1862 he patented and commenced the making of steam boilers by drilling the rivet holes through the two plates together after the plates are put into position.

He described punching as a barbarous mode of treatment, which destroyed the fibre of the material and led to accidents, and in his own works he never would allow any piece of metal to be subjected to treatment of this kind. As a boiler-maker and "manufacturing engineer," as he was accustomed to call himself, Mr. Adamson occupied an almost unique position. He was not by any means the largest boiler-maker in Great Britain, nor even in

Manchester, but he enjoyed a reputation second to none for the solidity and quality of his work and his extreme care in turning it out satisfactorily. He had every plate that was used subjected at his own works to the most careful tests, both chemical and mechanical. This fact, of course, enabled him to accumulate a great deal of experience as to the qualities of steel and iron which could be obtained in no other way, and the results of this experience were communicated to the Iron and Steel Institute in 1878, in a paper read at Paris "On the Mechanical and other Properties of Iron and Mild Steel." This paper was of a very elaborate and thorough character, and formulated certain laws and principles in reference to the qualities and manipulation of steel that have been of much subsequent service to the trade.

In 1863 and 1864 he erected the Yorkshire Steelworks at Penistone, and was part owner of the first works in this country to depend entirely on the making of steel on a large scale solely by Bessemer plant. At the annual meeting of the Iron and Steel Institute on the 9th of May, 1888, Sir Henry Bessemer, at the request of the Council, presented to Mr. Adamson the gold medal. Without in any way making an invidious comparison, Sir Henry said the unanimous decision of the Council to award the medal to their President met with his most cordial and entire approval. If they went back some thirty years, before the Iron and Steel Institute had spread new light among the manufacturers of iron and steel throughout this country, there was great difficulty in getting any of them to look at what was new and different from their old practice. He remembered how even in the stronghold of steel making, Sheffield, not one man could be found who sympathised with his process or had the smallest belief in his success. But fortunately for him—fortunately, he might add, for the world—there was outside of Sheffield a man who could appreciate it, a man who was determined at least to investigate it, to look into it on its own merits, to test it in every way that a practical man could test a new material. That man was his friend Mr. Daniel Adamson. Mr. Adamson convinced himself by actual trials how in his trade of boiler-making he could best treat the new material, whether he should punch or drill it, and how far it would bend and flange. Having convinced himself, he had the courage to adopt a thing which if unsuccessful would have ruined a reputation already made, and might have led to the most serious results.

In 1863 Mr. Adamson patented improvements in converters for Bessemer steel. In 1863 and 1864 he introduced improved blast engines for blowing Bessemer vessels with pistons with metallic surfaces. Up to the time of his death Mr. Adamson manufactured all classes of heavy machinery as well as general millwright work and hydraulic machinery, and was sole manufacturer for several American specialties, notably of engines fitted with the Wheelock automatic expansion gear, which obtained the grand prize in all competitions. The engine he exhibited at the Inventories Exhibition in London in 1885 gained the gold medal. Mr. Adamson had in recent years patented other inventions, such as compressing machinery, boiler furnace

and testing machinery, and at his works were testing machines from 30 to 2,000 tons power, for testing the breaking strength of bridge iron and other purposes. At the Edinburgh International Exhibition a gold medal was awarded to Messrs. Adamson for their horizontal engine, which had been used in connection with electric lighting machinery. Among his recent inventions is a labour-saving arrangement by which as many as twelve tools can be worked simultaneously on a 60-ton bed. Mr. Adamson also took an interest in the fight between guns and ships, and recently patented a new breech-loading gun, its principal characteristic being a new and effective arrangement of the breech. He has also from time to time written instructive papers on subjects of interest to the mechanical world, among which may be enumerated one on "Quadruple Expansion Engines," read before the Iron and Steel Institute in Manchester, at its meeting in 1875.

Mr. Adamson, though distinguished as a mechanical engineer, latterly became more known to the public from his connection with the Ship Canal scheme in its early stages. The conception may not have been his, but to him at any rate belongs the credit of having put the machinery in motion which made that practicable which, for more than half a century, had been a cherished dream. In June, 1882, he invited some of the leading citizens to meet at his residence, The Towers, Didsbury, "to consider the practicability of constructing a tidal waterway to Manchester, and to take such action thereon as may be determined on after a full discussion of the subject." A committee was appointed at that meeting, Mr. Adamson being chairman, for the carrying out of certain schemes, of which the outlines were submitted. It was found upon inquiry that any scheme for making a tidal waterway to Manchester from the sea was impracticable, and Mr. Leader Williams's scheme for constructing a canal with a series of locks was the only one to which, from a practical point of view, attention could be given. The subsequent history of the movement scarcely need be recapitulated.

No face or figure was more frequently to be seen at the meetings of the various societies representing applied science than those of Mr. Adamson. His manner of speech was strikingly earnest and original, and his matter was invariably worth listening to. The treatment of metals was his pet theme, and their properties, which are a necessary corollary, occupied an equally large share of his attention.

Mr. Adamson was elected a Life Honorary Member of the Association in March, 1884. He died 13th January, 1890.

Robert Nivin Cottrill, J.P., was born 5th April, 1842, and was the eldest son of Mr. John Cottrill, of Horwich. He was educated partly at Rivington Grammar School and partly under Mr. W. Sunderland, of Ashton-under-Lyne. He was afterwards articled to the business of an engineer and millwright, and in 1869 succeeded to the business of Mr. W.

Ryder, formerly of Bark Street, from which place he, in 1884, removed to the Beehive works.

Mr. Cottrill was always deeply interested in educational matters, and was associated with various departments of usefulness in the Borough of Bolton, politically and educationally, where his loss is deeply deplored.

He was elected an Honorary Member of the Association, September, 1886. He died 17th March, 1890.

Duncan Crighton joined the Association in the year 1857, as an ordinary member. In 1860 he held the position of Vice-President, and shortly afterwards was made a Trustee, which office he retained till the end of 1883, when owing to ill health he was compelled to give up those duties. He died 30th May, 1890, aged 73 years.

William Taylor was born on the 14th of July, 1854, and after finishing his scholastic education he entered the works of Messrs. A. Lees & Co., where he worked as pattern-maker, fitter, &c., both inside the works and also at various cotton mills, erecting and starting the machinery; thus he gained a knowledge not only of the making but of the practical working of the machines.

Shortly after reaching the age of 21 he was appointed foreman, and had at various times other departments put under his control, and was at the time of his death fully responsible for the management of the blowing room, card room, and ring and throstle spinning and doubling machinery departments. At the end of 1887 his health began to fail, and he was not able to attend much at the works for the last two years of his life.

Mr. Taylor was a frequent attender at the meetings of the Association, and always evinced the greatest interest in its proceedings. He was a member of the Committee of Management in the years 1887 and 1888.

He was elected an Ordinary Member of the Association, December, 1884. He died on the 8th March, 1890, deeply regretted by a large circle of friends and acquaintances.

Francis Bernard Welch, was the only member of the firm of F. B. Welch & Co., Engineers, Atlantic Works, City Road, Manchester. The deceased gentleman, who was only 37 years of age, was a son of the late Mr. John Welch, a special pleader of the Inner Temple. He came to Manchester about the year 1875, and after holding for a short time an appointment in Oldham, he established the practice of a consulting and mechanical engineer in Manchester, where he had the supervision of many large works.

He was elected an Honorary Member of the Association in June, 1885. He died 21st October, 1890.

REPORTS OF EXCURSIONS.

Manchester Ship Canal, Eastham Section.—On Saturday, 28th June, the members of the Association visited the Eastham section of the Manchester Ship Canal works, where they had an opportunity of inspecting the progress which has been made on this portion of the works since a previous visit of the Association a couple of years ago. The party which numbered about 150 members and friends, left Manchester by the 10-30 a.m. express, and arrived at Eastham shortly before one o'clock. Through the kindness of Mr. L. P. Nott and the executors of the late Mr. T. A. Walker, the contractor, special arrangements were provided to enable the members to make a thorough inspection of the whole of the works on the Eastham section, and they were conveyed by train along the entire length, from the above point to Ellesmere Port and back, frequent stoppages being made at the most important points of interest. The portion of the works which attracted the chief attention were the locks at Eastham, where the Ship Canal commences in deep water on the Cheshire side of the Mersey. Here three locks and two sluices are being constructed, the whole of the work being in a very forward state towards completion. The principal lock is 600ft. by 80ft., the intermediate lock 350ft. by 50ft., and the small lock 150ft. by 30ft., whilst the couple of sluices are each 20ft. wide. The party entered the locks at the Eastham end, where they had an opportunity of seeing the construction of two large storm gates, which have already been swung and are nearly completed. Passing on through the locks, they were met by the train in the canal cutting, and thence conveyed on to Ellesmere Port, where a short stay was made to enable the visitors to inspect the method of pile-driving now going on for the construction of the river wall, which is being built in the bed of the river along a considerable portion of this section. Returning to Eastham, the members sat down to tea at the Eastham Ferry Hotel, Mr. John West, the President of the Association, occupying the chair.

After tea the President, addressing a few observations to the members, expressed his regret that Mr. Alderman W. H. Bailey, one of the directors of the Ship Canal Company and a member of the Association, who had accompanied them upon their previous visit to the works, was unable to be present with them that day. Mr. Bailey had, however, written a letter, in which he expressed the confidence that, notwithstanding his absence, ample arrangements would have been made to promote the comfort of the members of the Association, who had been such good friends to the project. In all the campaign to get Parliamentary sanction their members had done more than any class of men in the district, and therefore they would obtain more satisfaction when it was ready for "those who go down to the sea in ships." He hoped to live to see the day when he might have the honour and pleasure of taking the society down the canal from Manchester to the tidal waters of the Irish Sea. The President added that he was sure all the members would

join in the hope to which Mr. Bailey had given expression in his letter, and that it would not be very long before it might be realised. They remembered their visit to the canal two years ago; they then saw many of the mechanical appliances in operation upon the work, which had only been recently commenced. That day they had been enabled to see the enormous amount of excavation which had been carried out, and the massive structural work which had been erected for the locks where the canal would enter the river. From an engineering and mechanical point of view they had every reason to be proud of the work which they had seen that day, and especially to members of that Association it was a great satisfaction to see so important a piece of engineering work being carried out to such a successful completion. He was sure they would all join with him in wishing that great undertaking every success. They believed it would be a great advantage to the district, and he hoped and trusted it would also be a great benefit to the shareholders.

Mr. Thomas Ashbury proposed a vote of thanks to Mr. L. P. Nott and the officials connected with the works for the facilities they had provided that day to enable the members to inspect the Eastham section. Unfortunately Mr. Nott had been unable to be present with them, but that gentleman wished him to say that it had afforded him the greatest pleasure to assist the members of that Association in any way in visiting the works. He might add that that was absolutely the last excursion which would be allowed to visit the Ship Canal works as a large party by a contractor's train. Within six or seven months he was informed that the Eastham section of the works would be practically complete, and that in every stage the work was well up to time. There were 44,000,000 cubic yards of excavation of soil and rock to be removed in forty-eight months, and that up to the present time satisfactory progress had been made, about 30,000,000 cubic yards having been excavated. There were 97 steam navvies engaged upon the work of excavation. Other plant upon the works included 169 locomotives, 245 steam cranes, 130 portable and other steam engines, 211 steam pumps, 6,160 wagons, 52 pile-driving engines, and the overland route of railway and sidings was 220 miles long. The steam power employed might be roughly estimated at about 50,000-horse power, and there were 169 horses and over 12,000 men and boys engaged upon the works.

The vote of thanks having been passed by acclamation, the proceedings terminated, and the party returned to Manchester.

Manchester Ship Canal, Manchester, Salford and Barton Sections.—On Saturday afternoon, 16th August, by the courtesy of Mr. E. Leader Williams, upwards of 100 members of the Association visited the Manchester, Salford and Barton section of the Manchester Ship Canal works, under the direction of the President (Mr. John West) and the ex-President (Mr. T. Ashbury) of the Association. The party assembled in the first instance, at 2 p.m., at the Pomona Docks, and thence proceeded to the Salford Docks,

and completed their inspection on Brindley's historic aqueduct at Barton. On the motion of the President a unanimous vote of thanks was accorded to Mr. Ashbury for the able manner in which he had described the various sections of the canal *en route*. Each member was supplied with a printed description of the different sections, and the afternoon being exceptionally fine, the meeting was a pronounced success.

Mr. Herbert Fletcher's Farnworth Bridge Colliery.—On Saturday afternoon, 6th Sept., the members of the Association, with a number of ladies, numbering 150 persons, paid a visit to the Farnworth Bridge Colliery of Mr. Herbert Fletcher, to inspect the apparatus there in operation for the prevention of the smoke nuisance arising from manufactories. The party left Victoria Station by special train at 3-7 p.m., and were received at the Colliery by Mr. Fletcher, who gave each of them a most cordial reception. The usual round of inspection was then made, and some of the members present devoted themselves to testing the working of the boilers with the mechanical stokers attached. The majority of the party descended the mine and made their way to the face of the coal, much interest being evinced by them in every thing to be seen there. Subsequently they embarked on a couple of barges which were fitted up for their accommodation and proceeded by the canal to a spot near the Hollins, where they disembarked.

During the journey Mr. Fletcher took his stand on the bridge of one of the barges, and all the while the journey lasted entertained the company with a lecture on the smoke nuisance question, dealing with his subject in a technical style. Tea was awaiting them in the 'old barn' attached to Mr. Fletcher's quaint residence, and they were royally entertained. After tea a brief interval was spent in the inspection of the interior of the house and a stroll on the well-kept lawn, after which Mr. Fletcher gave a smart little dance to his guests. Several ladies and gentlemen appeared in fancy costumes, and some of the visitors making slight changes in their attire, the scene, as the first quadrille was performed, presented a charming variety of colour, and was one which was thoroughly enjoyed by all.

After the quadrille Mr. West rose and proposed a vote of thanks to Mr. Fletcher, saying he was doing a great deal in the cause of humanity, and was pursuing a very worthy object, and one that was capable of being attained. He (the speaker) was satisfied that it could be accomplished, and believed with Mr. Fletcher that it would be accomplished in a very short space of time. The district was very much indebted to Mr. Fletcher for his practical demonstrations to engineers and steam users. The question of combustion had been known many years, but how to apply it had been a difficult task, and various methods and schemes had been devised, but it was a long time before the public or steam users would use them with a will and determination. There were many difficulties in the way from a chemical point of view, but he was satisfied that steam users, with the material they were using, could prevent the smoke nuisance. He believed

the time had come now that men had shown how it could be accomplished, that an effort should be made to clarify the atmosphere. Manufacturers should not be allowed to send forth from their chimneys particles of carbon, which did such a great amount of harm to vegetation and to human life. That afternoon they had made a few experiments with the boilers, which were of the Galloway type, and found that the rate of evaporation was 6,857lbs. of water per hour on a stated consumption of 768lbs. of coal, or 8·91lbs. of water evaporated per 1lb. of coal, at an average pressure of 73lbs. When they took into consideration the coal used—being one-third dirt—they must come to the conclusion at once that this was a very good result indeed.

Mr. Ashbury seconded the proposition, and said Mr. Fletcher was a philanthrophist, and had shown the way to the banishing of one of the greatest nuisances we had in this kingdom. They as an Association of engineers had learnt something that day, and he trusted the day was not far distant when in every town would be put in force compulsory measures for the suppression of the smoke nuisance. Smoke could not be consumed, it must be prevented, for once it was made it must go on, with its deleterious effects.

The motion was carried with much enthusiasm.

Mr. Fletcher replied in his characteristic manner, and emphasised his remarks by reading an article by 'Hotspur' in the Bolton *Weekly Guardian*, dealing with the question of smoke nuisance, and referring to the stand he had taken in regard thereto. He also stated that the Sanitary Committee of the Corporation had determined to prosecute without delay anybody making dense or 10 minutes' moderate smoke, believing that the time had come when they should take a decided action in this matter.

TREASURER'S GENERAL CASH ACCOUNT, FOR YEAR ENDING 31st DECEMBER, 1890.

Dr. *(Including Superannuation Fund Account.)* **Cr.**

1890.		£	s.	d.
Jan. 1.	To Balance as per last Report	2872	14	9
Dec. 31.	„ Contributions and Entrance Fees	527	7	4
	„ Transactions—sold	29	3	2
	„ Interest from Loans in Building Societies £23 0 0			
	„ „ „ Mortgages on Properties 55 10 0			
	„ „ „ Stock—Salford Corporation 17 1 2			
	„ „ „ Bank 6 13 9			
		102	4	11
		£3531	10	2

Audited and found correct,

JOS. NASMITH,
T. CRYER,
W. J. JENKINS,
} AUDITORS.

30*th Aug.*, 1890.
7th Jan., 1891.

1890.		£	s.	d.
Jan. 1.	By Rent—Grand Hotel	20	0	0
to	„ Secretary's Salary £22 10 0			
Dec. 31.	„ Librarian's „ 7 10 0			
		30	0	0
	„ Superannuation Allowance	115	1	0
	„ Printing and Stationery	137	5	0
	„ Books purchased for Library	4	19	6
	„ Insurance premium on Library	0	6	0
	„ Deputations to London, Leeds & Middlesboro' Associations	6	10	0
	„ Thirty-fourth Anniversary Dinner	12	4	6
	„ Audit and Committee Expenses, Postage and Petty Cash and Expenses in connection with Social Meeting	57	18	0
	„ Loss in Consolidated Building Society	52	8	2
	„ Travelling Expenses to Mr. D. B. Donald, *re* paper on Steam Cranes	3	3	0
	„ New Library Case	28	19	0
	„ Cash Invested as Loans in Building Societies... 720 0 0			
	„ „ Advanced on Properties (Mortgages) 1650 0 0			
	„ „ Salford Corporation Stock 500 0 0			
	„ „ in Bank 141 18 11			
	„ „ „ Treasurer's hands 27 8 3			
	„ „ „ Secretary's „ ... 23 8 10			
		3062	16	0
		£3531	10	2

SUPERANNUATION FUND ACCOUNT, FOR YEAR ENDING 31st DECEMBER, 1890.

Dr. *(Included in General Account.)* **Cr.**

1890.		£ s. d.	£ s. d.
Jan. 1.	To Capital invested as per Resolution passed at the Half-yearly Meeting, 14th June, 1879 ..	2100 0 0	
	,, Additional Capital voted at the Annual Meeting, 13th December, 1884.....	300 0 0	
	,, Balance of Interest from last Report	23 3 4	
			2423 3 4
Dec. 31.	,, Twelve Months' Interest on Capital Invested as per General Account		102 4 11
			£2525 8 3

1890.		£ s. d.	£ s. d.
Jan. 1. to Dec. 31.	By Superannuation Allowance:—		
	Mr. O. Williams	16 18 0	
	,, W. Mc.George	16 18 0	
	,, J. R. Wolstenholme	14 19 0	
	,, R. Pearson	16 18 0	
	,, F. Meixner	15 12 0	
	,, G. Vickers.....	16 18 0	
	,, W. Holmes	16 18 0	
			115 1 0
	,, Balance to credit of Superannuation Fund Account		2410 7 3
			£2525 8 3

Audited and found correct,

JOS. NASMITH,
T. CRYER,
W. J. JENKINS,
} AUDITORS.

7th January 1891.

UNIVERSITY OF ILLINOIS-URBANA
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